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NWC TP 5902

Low Cost Servo Actuator for Tactical Missile Thrust Vector Control (TVC)

by
R. Levi
P. H. Stahlhuth
Aeronutronic Division
Aeronutronic Ford Corporation
for the
Propulsion Development Department

MAY 1977

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FOREWORD

This report describes the design, development, fabrication and testing of cold gas driven, closed-center servo actuator systems for operation of a trapped ball type of movable nozzle thrust vector control system for tactical missiles. This investigation was conducted during the period 22 April 1976 to 19 October 1976. The work was sponsored by the Naval Weapons Center (NWC), China Lake, California, under Navy Contract N00123-76-C-0286 and supported by the Naval Air Systems Command under AirTask A03W3300/008B/6F31330300.

Mr. Michael J. Ripley was the Navy Technical Coordinator and has reviewed this report for technical accuracy.

This report is released for information at the working level and does not necessarily reflect the views of NWC.

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TECHNICAL SUMMARY

A cold gas driven, closed-center servo actuator has been developed to operate a trapped ball type nozzle assembly on a tactical missile. One engineering test model and six flight-weight units have been delivered. Figure 1 shows the actuator assembly. Helium at a 2000 psi regulated pressure drives the balanced area actuator. The helium flow to each side of the piston is controlled by a pair of three-way electromagnetic flapper valves which are Pulse Duration Modulated (PDM) at 100 Hz. When fully "on", a valve vents its end of the cylinder, closing the inlet port. When fully "off", the cylinder is pressurized at the valve inlet pressure. A linear position feedback transducer (potentiometer) is mounted on line with the piston. The control valve PDM ratios are commanded by an electronic controller in response to errors between the input command and the output position. Table 1 compares the specified performance requirements and the measured performance of these actuators. Figure 2 shows a Bode plot of the actuator operating at full load on room temperature helium. The servo system performance was characterized for operation on both helium and nitrogen gas supplies. The actuator met predictions of slew rate, frequency response, and helium flow rate.

A proposed installation of this type of actuator on a trapped ball nozzle and blast tube is seen in Figure 3. This drawing shows one means of packaging multiple small high pressure (10,000 psi) helium bottles in a cluster around the blast tube, along with the required squib valve, pressure regulator, and other attendant hardware.

This program was conducted under NWC contract N00123-76-C-0286, according to the Milestone Chart shown in Figure 4.

FIGURE 1. Servo Actuator Assembly.

TABLE 1. Actuator Performance.

Item	Specification	Actual
Nozzle Deflection	±20°	±20°
Stroke	±0.82 in.	±0.82 in.
Moment Arm	2.40 in.	2.40 in.
Load Inertia	13-15 lb-in^2	14 lb-in^2
Slew Rate	400 deg/sec	500 deg/sec max for hard over step command
Servo Bandwidth ±10% Amplitude	15 Hz (-3db or -90° phase lag)	16.5 Hz (-3db and -30° phase lag)
Minimum Damping Ratio (200 to 700 in-lb load)	0.3	0.38 (+2.4db peaking at 200 in-lb load)
Flow Rate at 15 Hz, ±10% Amplitude Sine Commands	0.015 lb/sec	0.0125 lb/sec
Hysteresis-Resolution (700 in-lb load)	1° max	0.4° (typical)
Maximum Electric Power Consumption	35 watts	34 watts
Actuator Weight (ea)	3.00 lb max	1.39 lb
Nozzle Friction Load	200-700 in-lb	200-900 in-lb
Actuator Stall Torque	...	2928 in/lb
Specified Duration (at -40°F)	17 sec	...
Specified Duty Cycle for Two Actuators - Total Activity	625°	...

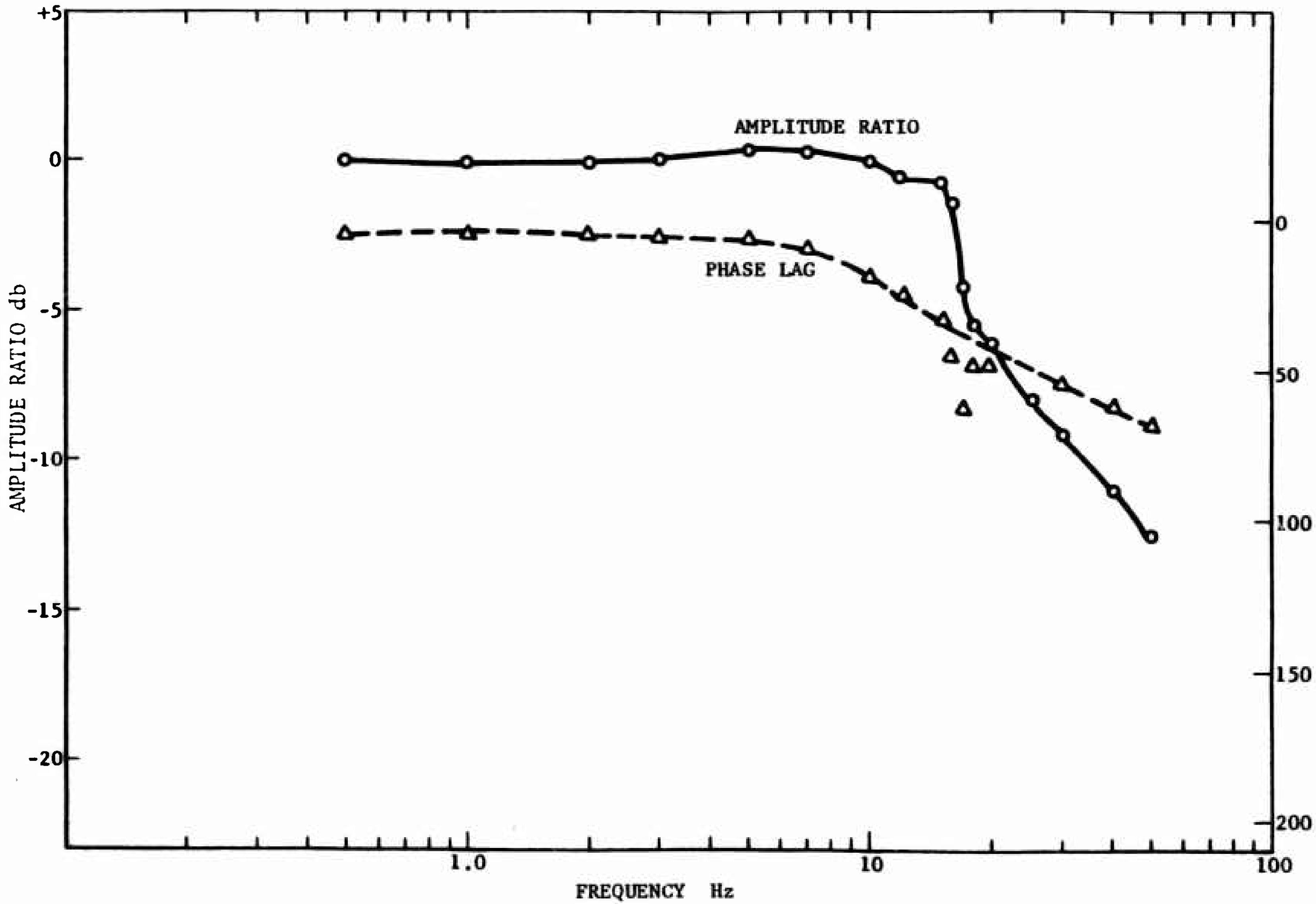


FIGURE 2. NWC Actuator Frequency Response on Helium (Gain 0.58/100%) - High Load.

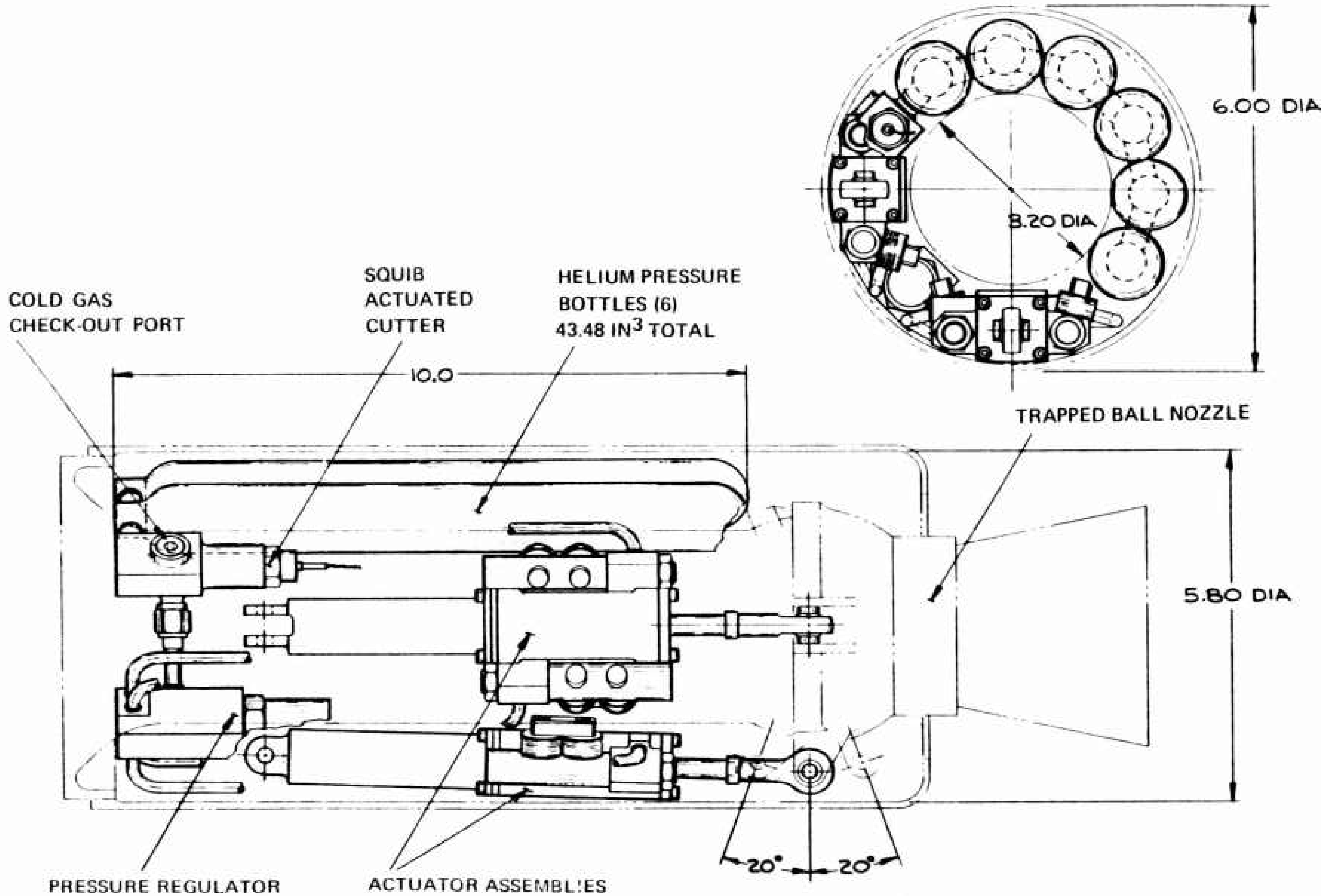


FIGURE 3. Low Cost Servo Installation – Rear Mounted Helium Power Supply.

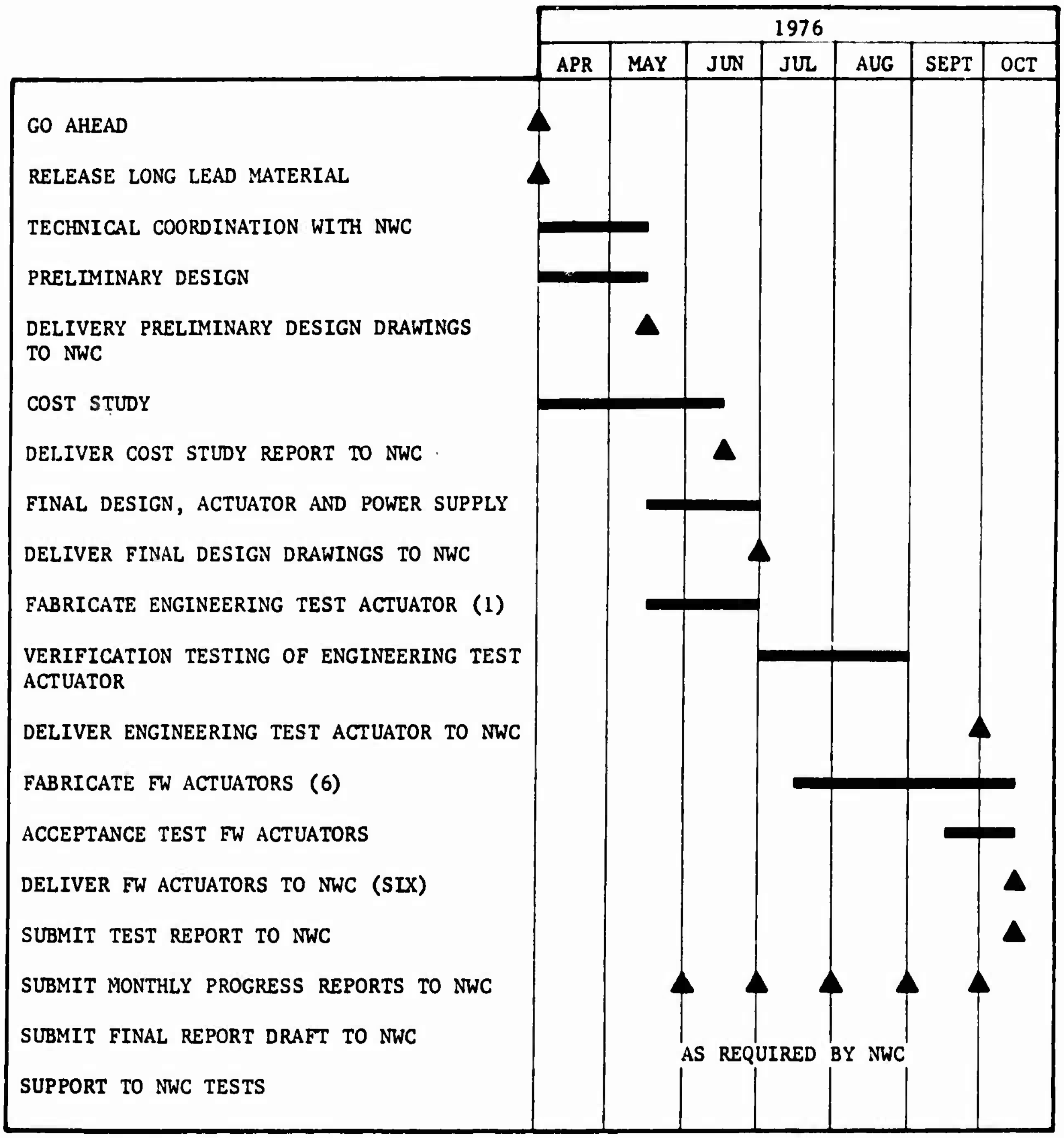


FIGURE 4. NWC Servo Actuator Schedule.

SYSTEM DESCRIPTION

The closed-center pneumatic nozzle actuator is designed to operate a trapped ball nozzle assembly in response to an applied electrical command. An integral position transducer is used as the feedback element in a closed loop control system. Helium was selected as the working fluid because of the higher response characteristics it provides.

The actuator is shown schematically in Figure 5. The drawing of Figure 6 shows the details of the control valves and the actuator assembly. Design and operating characteristics of the actuation systems are listed in Table 2.

The individual actuator assemblies each comprise two three-way valves, a double-acting piston/cylinder assembly, and a potentiometer position transducer. A spherical rod-end bearing on the piston rod and a clevis on the housing provide means for attachment to the nozzle and motor aft closure, respectively. An exploded view is seen in the photograph of Figure 7.

To obtain pitch and yaw control of the TVC nozzle, two actuators are used. The power supply comprises one or more hermetically sealed pressure vessels (depending on the installed location), an explosive actuated valve, and a pressure regulator (see Figure 3).

The two actuators are each mounted on the blast tube with clevis fittings that allow for slight angular motions of the actuators resulting from X and Y coordinate motions of the nozzle attachment fittings. Since the nozzle lugs are located in the same plane as the nozzle spherical seal centerline, each actuator's angular motion occurs only in one plane. No significant cross talk occurs between the actuators. The slight angular motion (±0.6 degree) of each actuator requires that the gas inlet tubes have sufficient length to permit a small amount of flexing. The package arrangement requires inlet tube lengths from the gas distribution manifold which are adequate to provide the required flexibility.

LOAD DEFINITION

Two identical actuators are used to operate the trapped ball nozzle in two planes. The nozzle deflection can be up to ±20 degrees in any plane. The moment arm at the nozzle attachment point is 2.40 inches, requiring an actuator stroke of ±0.82 inch. The specified nozzle inertia is 13 to 15 in^2-lb or 0.0363 in-lb-sec^2. The specified maximum slew

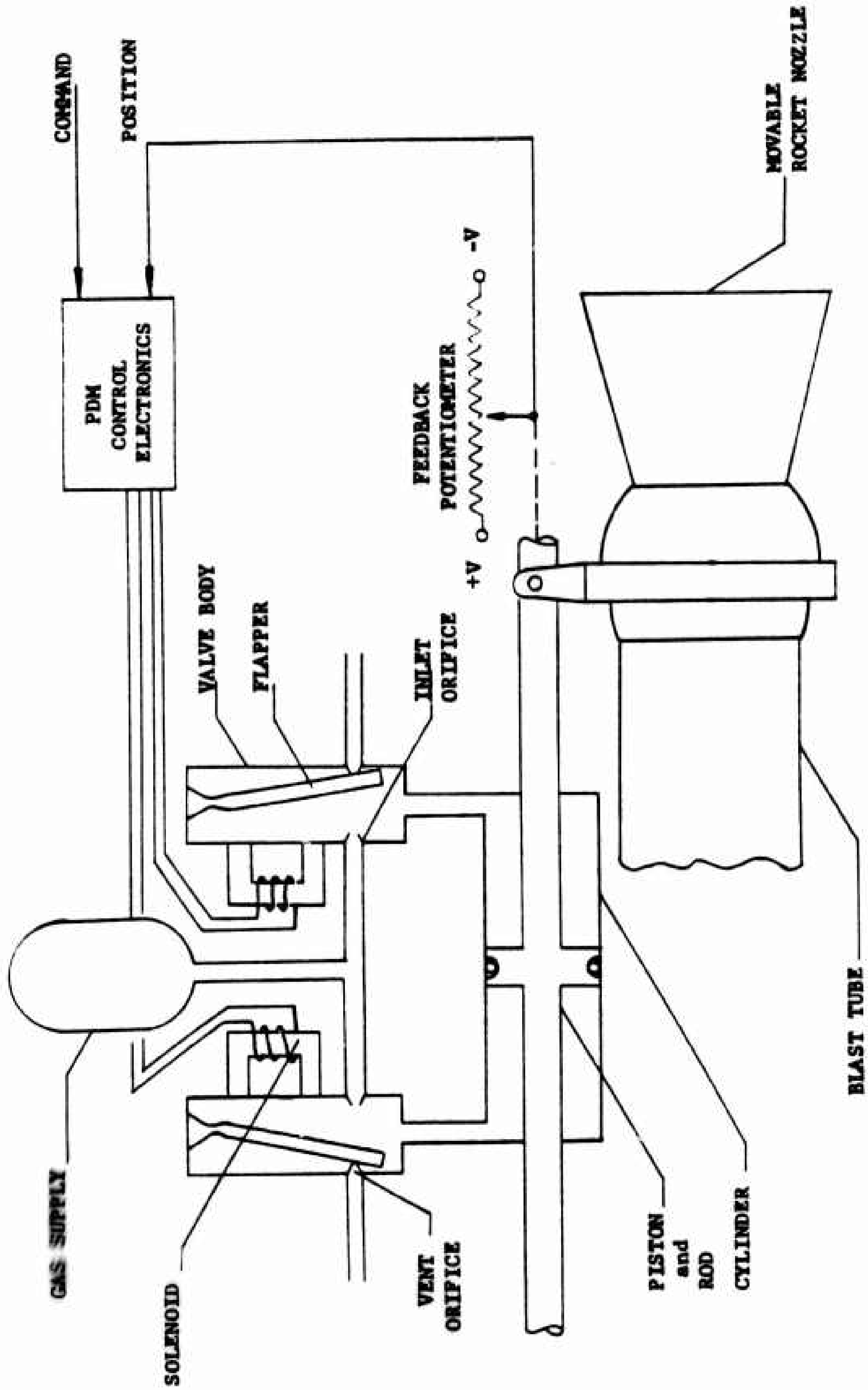


FIGURE 5. Closed-Center Pneumatic TVC Actuator.

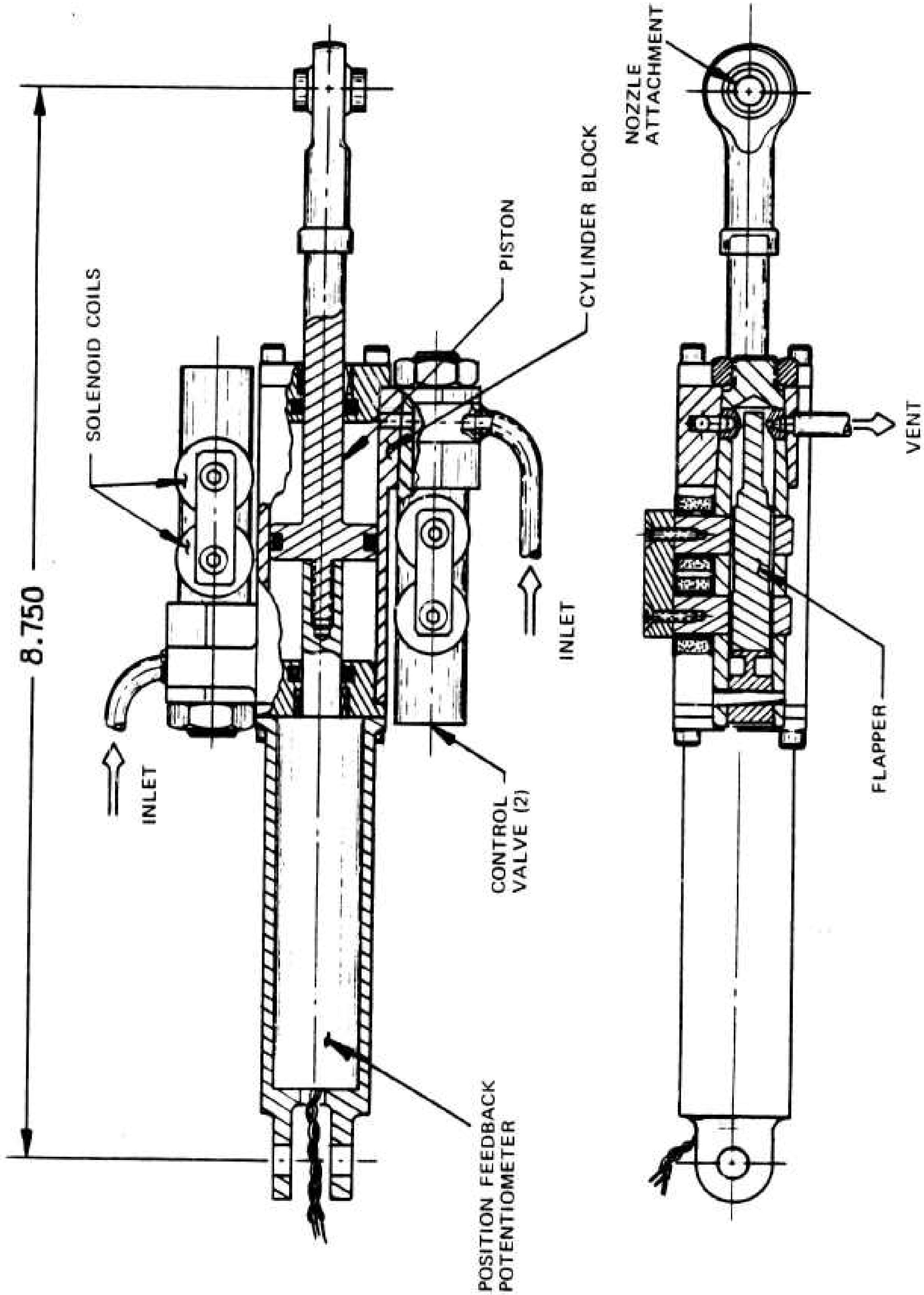


FIGURE 6. Low Cost Actuator Assembly.

TABLE 2. Actuator Design Summary.

Item	Value
Nozzle Travel	±20 degrees
Moment Arm	2.40 in
Stroke	±0.82 in
Load Inertia	14 lb in.^{2} (0.0363 in-lb-sec^2/rad)
Load Torque	200-700 in-lb
Maximum Slew Rate	500 deg/sec
Servo Bandwidth (±10% Amplitude)	16.5 Hz (-3db)
Position Resolution	0.4 degree
Piston Diameter	0.937 in.
Rod Diameter	0.312 in.
Effective Area	0.61 in.^{2}
Inlet Gas Pressure	2000 psig
Maximum Stall Force	1220 lb
Control Valve Orifice	0.038 in. diam
Orifice Flow Coefficient	0.65
Design Flow Rate	0.015 lb/sec
PDM Frequency	100 Hz
Valve Coil Resistance	23 ohm
Coil Voltage	28 vdc
Valve Current Per Actuator	1.22 amperes
Actuator Assembly Weight	1.39 lb
Installed Length	8.75 ±0.81 in.
Duration	17 sec
Duty Cycle - Total Activity For Two Actuators	625°
Storage Volume - Helium at 10,000 psi, 140°F	30-60 in.^{3} depending on type of duty cycle
Regulator Flow Rate	0.030 lb/sec

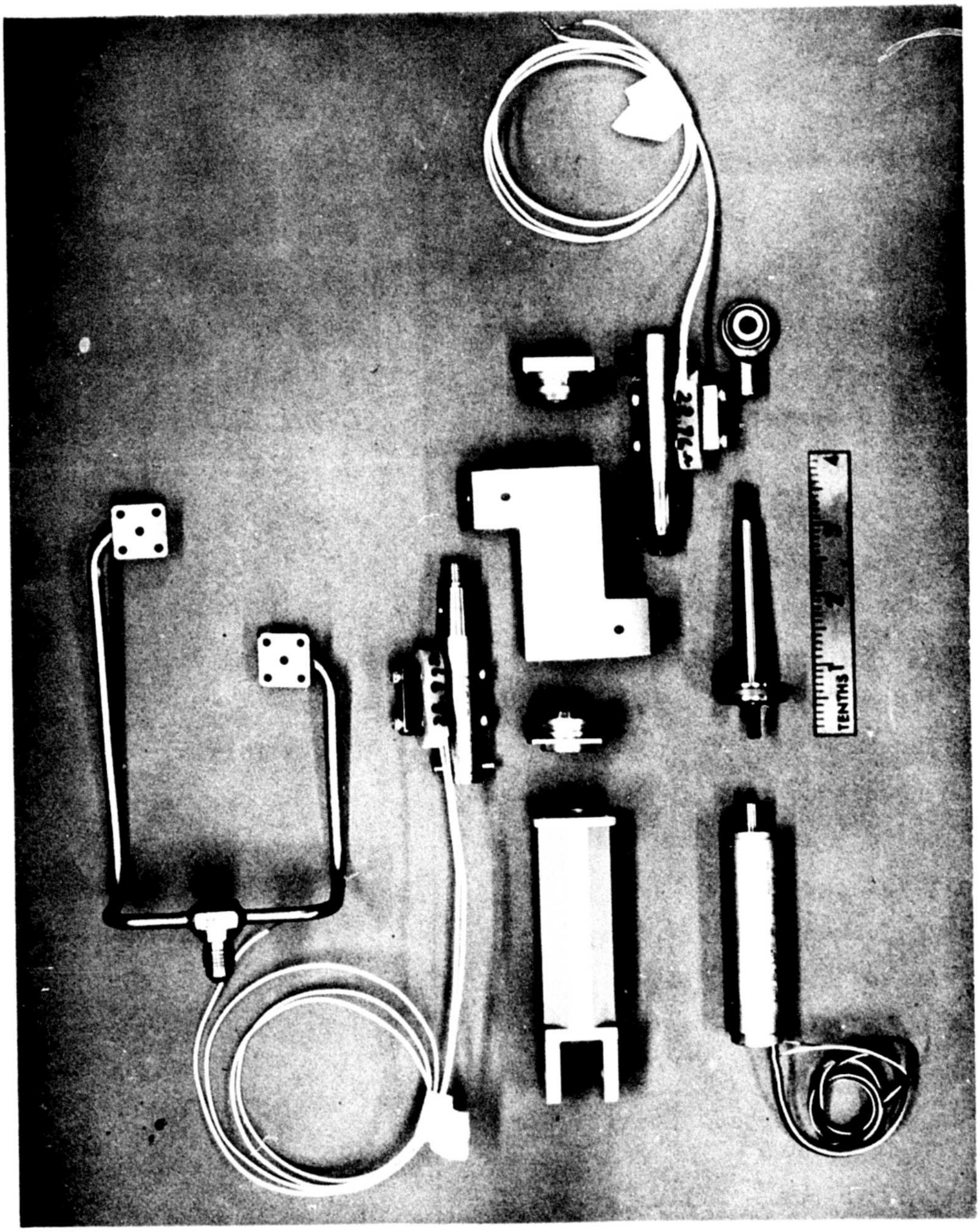


FIGURE 7. Servo Actuator - Explored View.

rate is 400 degrees/second. The trapped ball nozzle torque load is primarily coulomb friction ranging from 200 to 700 in-lb. The minimum required frequency response of the nozzle actuator system is 15 Hertz at ±10 percent amplitude command (±2 degrees) with a maximum of 90 degrees phase lag or -3db amplitude ratio, whichever occurs first. The operating duration of the servo system is 17 seconds and the duty cycle requirement includes a total activity for the two actuators of 625 degrees of nozzle motion.

MECHANICAL DESCRIPTION

The closed-center nozzle actuator assembly is shown in Figure 6. Electrical connections are required for the position transducer and the control valves. The cold gas power supply will be connected at the point marked "inlet" on the drawing.

CONTROL VALVES

Two control valves are used on each actuator. These are three-way valves with the inlet-to-cylinder passage normally open and the cylinder-to-vent passage normally closed when pressurized.

Each valve has a flexurally mounted armature (flapper) within a cylindrical body which incorporates magnetic pole pieces and restrictors. The flapper is an assembly made of iron/cobalt magnetic material resistance welded to a heat-treated stainless steel flexure and tapered mounting piece. The valve body is made of type 347 stainless steel with magnetic pole pieces brazed in place. Valve seat orifices of 347 stainless steel are threaded into the body, staked, and sealed with Loctite to prevent movement and leakage. The orifices have a throat diameter of 0.038 inch.

The valve coil assembly consists of two individual coils, each wound with 417 turns of #33 magnet wire. The two coils are connected in series to provide the actuating force for the flapper. The total coil resistance is 23 ohms. The coils are encapsulated in epoxy potting compound to prevent damage to the coils and to help anchor the lead wires.

ACTUATOR CYLINDER ASSEMBLY

The actuator uses a balanced-area double-acting piston operating in an aluminum cylinder block. The cylinder block has provision for mounting the two control valves and contains internal flow passages to duct gas to valves and cylinders. O-ring seals are used on the piston, around the piston rods, and on the cylinder end caps. Teflon slipper seals are used to minimize breakaway friction on the piston and rod O-rings. The effective piston area is 0.61 in^2. The housing and cylinder is 7075 T6 aluminum with a solid film lubricant deposited on the cylinder bore.

The control valve mounting seats are an integral part of the cylinder block. The end of the valve bodies are tapered and fit into matching tapers in the cylinder block. Teflon tape seals are installed between the valves and the cylinder block to prevent leakage and cross-flow between ports.

Lock nuts on the outside of the cylinder hold the valves in place and maintain a preload on the seals. Pressure taps in the ends of the valve bodies are provided to monitor valve body pressure for testing purposes. Gas flow to and from the valves is through passages drilled in the cylinder block.

The actuator piston is made from type 416 stainless steel, heat treated to a hardness of 34 Rockwell C. The nozzle-end piston rod is machined as an integral part of the piston. The outer end of this rod is threaded to accept a rod end bearing. A dummy piston rod is used at the other end to pressure balance the effective piston area so that equal forces are generated by equal pressures acting on both sides of the piston. This second rod, which is threaded onto the piston, is integral with the position transducer, as described below.

All dynamic O-ring seals are Viton with Shamban Glyd rings.

The NMB piston rod bearings are Teflon impregnated fabric mounted in aluminum housings. The sleeve bearings for the piston rods are mounted in the cylinder end caps with a light press fit.

POSITION TRANSDUCER

The position transducer is a linear potentiometer mounted concentrically with the piston in the lower end of the actuator, as shown in Figure 6. A unique feature of this installation is that the potentiometer shaft is the same size as the nozzle-end piston rod; when it is threaded onto the piston the area of this shaft reduces the piston area by the same amount as the piston rod. This provides equal areas on both sides of the piston. The potentiometer was made by Bourns for this application.

The transducer uses a ceramic resistance element and a precious metal slider pickoff, both mounted in a common housing. The housing mounts in a bore in the lower end of the actuator; it is retained by a shoulder at one end of the bore and by the cylinder cap at the other end. Electrical leads are brought out of the actuator next to the clevis at the lower end of the unit.

ACTUATOR OPERATION

The closed-center actuator concept was selected for this application because it minimizes gas consumption by requiring gas flow only when a new position is commanded, providing the most efficient gas usage. In addition, higher servo bandwidth can be obtained than with a similar size open-center actuator.

The actuator schematic, Figure 5, shows the actuator in the pressurized and de-energized condition (no electrical command applied). For this condition the control valve flow passages from inlet to cylinder are normally open, and the vent ports are normally closed. Gas from the power supply enters each actuator inlet and flows through the valve inlet ports into the cylinder cavities on both sides of the piston. Since there is no vent flow the pressure on each side of the piston builds up to regulated supply pressure. Both sides of the piston have equal area, therefore there is no net force generated by the actuator and the piston will remain in position. When the cylinder is fully pressurized there is no further flow demand on the power supply, hence the description "closed-center" actuator.

When a new actuator position is required, one control valve vents gas from its side of the piston in response to an electrical command. The other valve has no command applied. It remains as shown in Figure 5, and the pressure on that side of the piston remains at the original supply pressure level. The resulting pressure differential across the piston generates the force necessary to move the piston to the commanded position. When the new position is reached the electrical command is terminated so that both valves are again de-energized, the previously vented cylinder pressure builds up to supply pressure level, and the piston remains at rest with no gas flow demand.

Since the load characteristic of the trapped ball nozzle is primarily coulomb friction with essentially no spring component, a significant actuator force is always required to move the nozzle or, conversely, the nozzle will remain at its last commanded position unless acted upon by a significant actuator force. This load characteristic permits use of the closed-center actuation system to full advantage.

VALVE OPERATION

The moving element in the control valves is a cantilevered flapper which is pressure loaded against the vent orifice in the absence of a command. When an electrical command is applied to the valve the magnetic force generated by the solenoid pulls the flapper away from the vent orifice and seats it on the inlet orifice. This seals the inlet and opens the vent port. When the command is removed, the combined action of the inlet pressure and the cantilever spring force move the

flapper away from the inlet orifice. The pressure times vent area force then forces the flapper against the vent orifice.

The command used on the control valves is a Pulse Duration Modulated (PDM) signal which is proportional to an input analog voltage command. In PDM operation the valve flapper cycles between the vent seat and the inlet seat at a constant cyclic rate (the PDM frequency). The flapper dwell time on either seat can be controlled from 0 to 100 percent of the cycle period. The PDM command is expressed on a scale from 0 to 100 percent where 0 percent represents continuous dwell on the vent seat (no command applied), 100 percent represents continuous dwell on the inlet seat (full dc command), and any command between 0 and 100 results in the flapper dwelling part of the cycle time on the inlet seat and the remaining part of the cycle time on the vent seat. Since the flapper motion time is extremely short, the relationship between percent PDM command and dwell time on the inlet seat may be expressed as

$$\%PDM = \frac{t_{in.}}{t_{in.} + t_{vent}} \quad \text{or} \quad \frac{t_{in.}}{1/f}$$

where

$t_{in.}$ = dwell time on the inlet seat, sec

t_{vent} = dwell time on the vent seat, sec

f = PDM frequency, Hz

A zero percent PDM command applied continuously will result in full cylinder pressure. A 100 percent command applied continuously will result in zero cylinder pressure since the vent is open continuously. A command between zero and 100 percent, applied continuously, will result in an intermediate cylinder pressure since the control valve modulates the flow into and out of the cylinder.

Remembering that each control valve establishes pressure on one side of the piston, it can be seen that, with appropriate commands to the two control valves, the actuator piston can be moved in either direction at any desired rate up to the maximum permitted by gas flow capability. A 100 Hz PDM frequency has been selected to meet the performance requirements and to provide smooth actuator motion.

ELECTRONIC CONTROLLER

Figure 8 shows the control system block diagram used for the closed center actuator. Each valve is controlled by a separate electronic driver (a transistor switch with current control) and PDM modulator with gain control. The separate modulators provide the capability of controlling the loop gain, depending on the direction of motion. Since there will be some variation in the performance of any two control valves, the controllable electronic gain permits matching of the overall loop gain regardless of which valve is modulating. This provides symmetrical actuator performance without imposing the requirement of precise control valve matching.

During actuator operation one valve is modulated to cause the piston to extend and the other valve is used for retract motion. A position error signal is formed by taking the difference between the commanded position and the actual position; the magnitude or absolute value of the error signal is applied to each modulator through the appropriate gain. The valve to be modulated is selected by the error sign detector which inhibits the valve driver for the "off" valve. The sign detector operation is designed to be consistent with negative feedback. The sign detector switches command from one valve to the other as the error signal passes through zero and changes sign.

Each modulator also contains a "crossover bias" adjustment that is used to prevent any valve operation until the error signal reaches a preset value. This capability can be used to create a deadband to prevent sporadic switching between valves for small error signals.

Figure 9 shows the laboratory controller used. The mechanization of the controller is shown schematically in Figure 10. This controller used discrete components with hand wired circuit boards and plug-in operational amplifiers. Since space is not at a premium in a laboratory controller, the convenience of having access to the circuitry dictates this type of construction.

For bench testing or static firings it is suggested that a controller similar to this be used by NWC. For flight use, the controller would be redesigned to use hybrid circuits, integrated circuits, and other space-saving, environmental resistant techniques.

For small quantities of flight hardware, a package similar to that shown in Figure 11 might be developed. This figure shows the Flight Servo Control assembly for the Aeronutronic Stinger Alternate missile. This package is 3.3 inches OD, 2.0 inches ID, and 2 inches long, and contains all the control circuitry for four individual fin actuators. Printed circuit boards are used, with hand wiring between individual components, hybrid circuit packages, and film resistors.

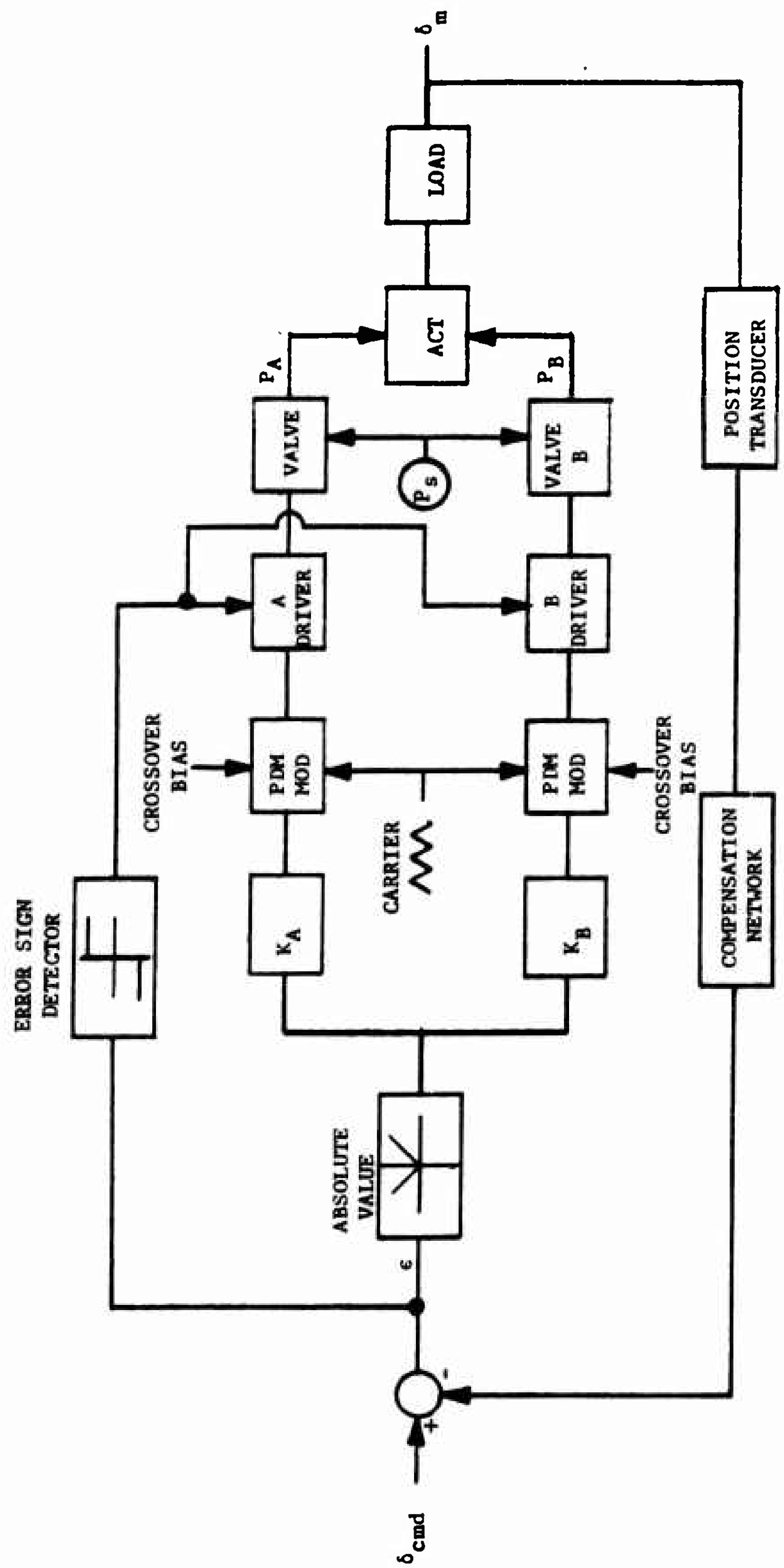


FIGURE 8. Block Diagram.

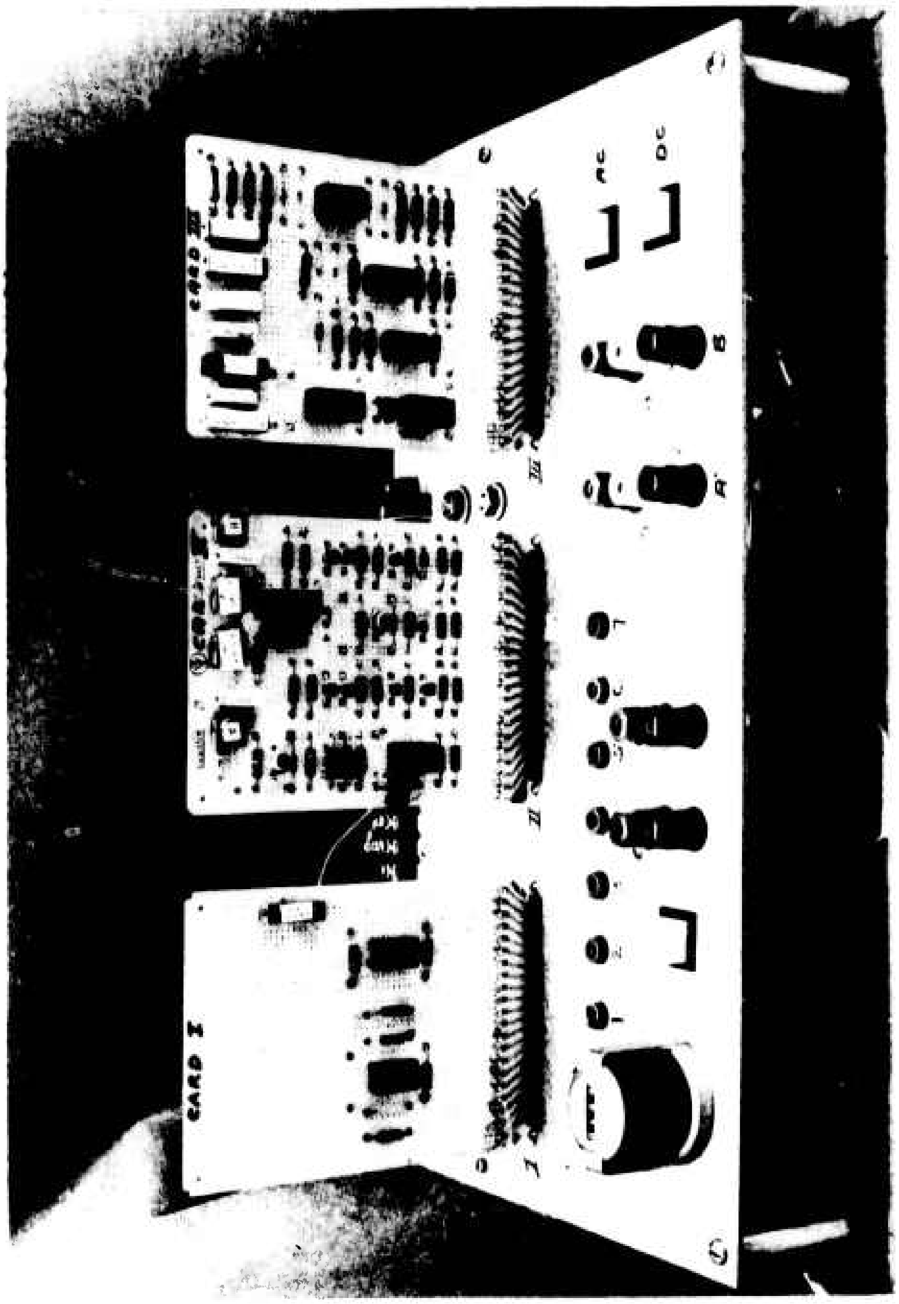


FIGURE 9. Existing Laboratory Controller.

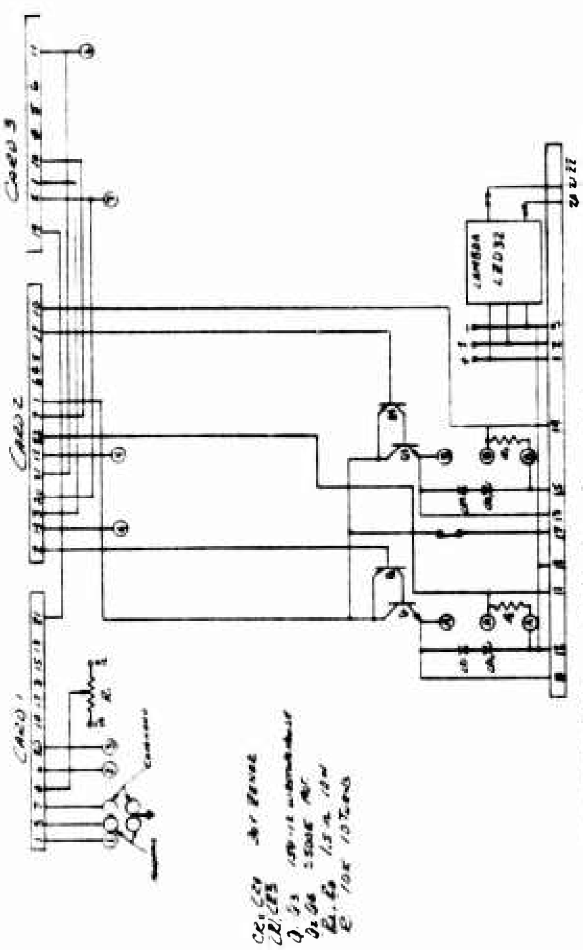


FIGURE 10a. NWC Nozzle Actuator Controller Chassis

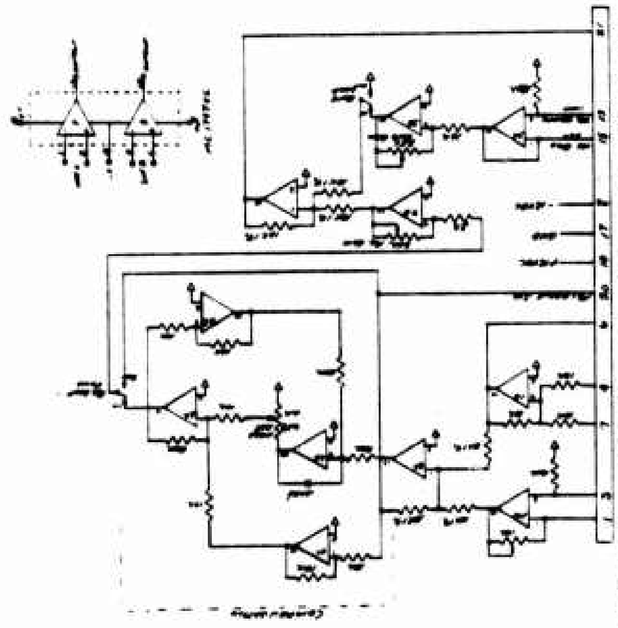


FIGURE 10b. NWC Nozzle Actuator Controller Card 1

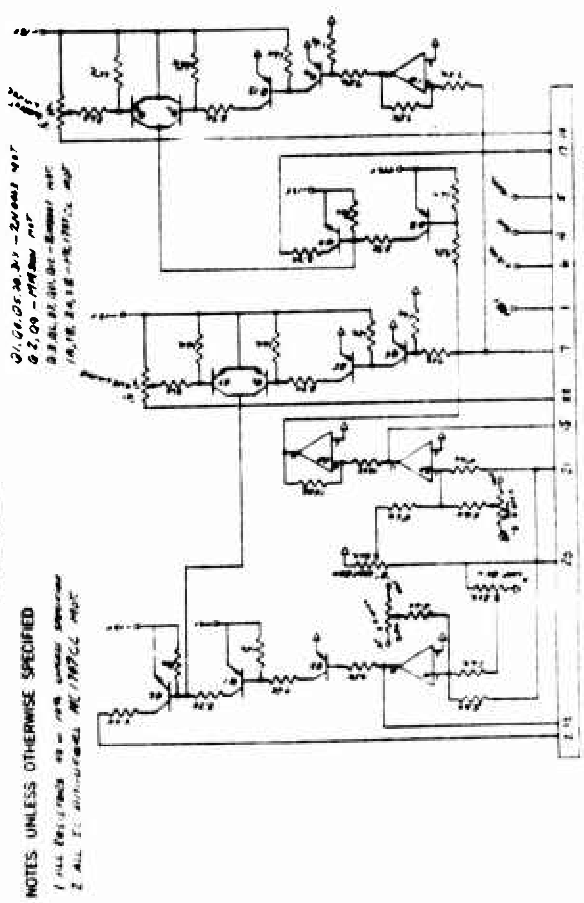


FIGURE 10c. NWC Nozzle Actuator Controller Card 2

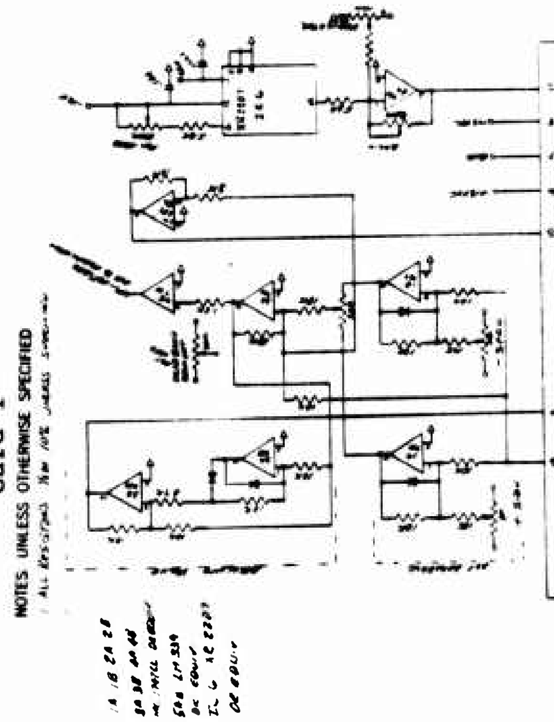


FIGURE 10d. NWC Nozzle Actuator Controller Card 3

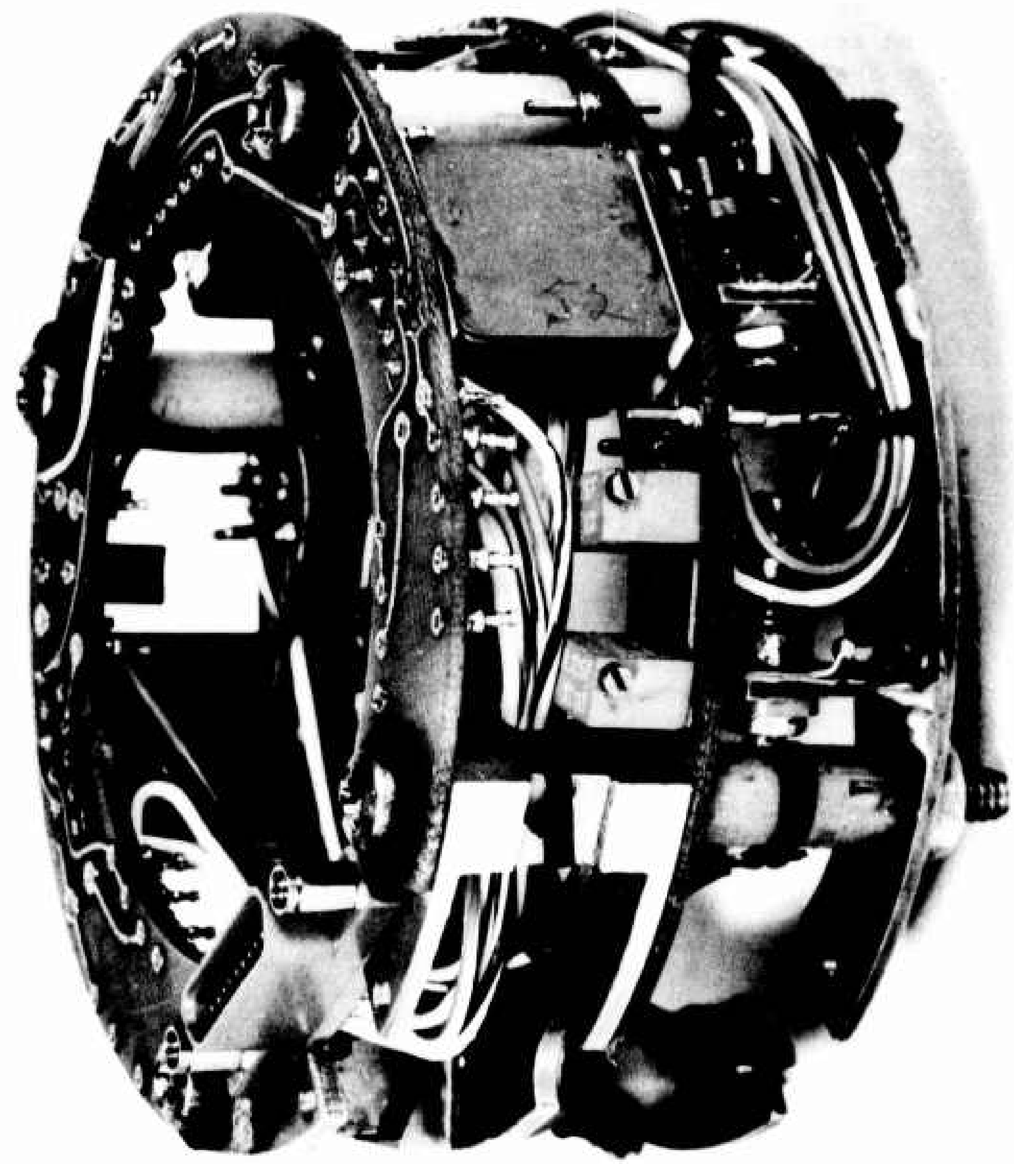


FIGURE 11. Stinger Alternate Flight Control Electronics.

In production quantities, this package size can be further reduced by the use of integrated circuit chips and circuit boards designed for more automated assembly. In production, these circuits would probably be integrated into other electronic modules on the missile.

WEIGHT

Each actuator assembly includes the inlet manifold from the 1/4-inch inlet fitting, the actuator housing, values, output rod and rod end bearing, and position feed back potentiometer. This assembly weighs 1.39 pounds.

DESIGN ANALYSIS

The actuator sizing analysis is presented in this section.

The Parameter List of Table 3 is used to identify variables in the calculations presented below.

ACTUATOR SIZING

Gas Flow Rate Determination

To determine the size of the control valve orifice, it is necessary to determine the maximum instantaneous flow rate required by the actuator. Each component of the required gas flow is calculated below.

Friction Flow Rate - Direction Reversal. When operating the servo in response to a sine wave command, it is necessary to reverse direction at the end of each cycle. With a large coulomb friction load, the differential cylinder pressure must be reversed at the end of a cycle from a value to overcome friction in one direction, to a value to overcome friction in the opposite direction. The friction load always acts to oppose motion. If it is desired to follow a sinusoidal command of a certain frequency with an effective phase lag of 90 degrees, then a required pressurization rate for the cylinder is defined. Figure 12 illustrates the command and actual position at the frequency where 90 degree phase lag is desired.

The required pressurization rate can be defined as follows: The applied torque necessary to overcome friction must change from $+\tau_F$ to $-\tau_F$ as the position changes direction (velocity changes sign). For the

TABLE 3. Parameter List,
Closed Center Actuator.

Symbol	Item	Value
$\dot{\theta}_m$	Maximum slew rate (specified)	400°/sec
τ_F	Load friction torque	200 to 700 in-lb
J	Nozzle inertia	13 lb-in^2 or 0.034 $\frac{\text{in-lb-sec}^2}{\text{rad}}$
θ_m	Maximum vector angle	±20°
ℓ	Moment arm @ 0°	2.4 in.
χ	Linear stroke	±0.82 in.
T	Rankine gas temperature	460° + °F
R	Specific gas constant	4635 in./°R (Helium)
f	Frequency	Hz
ω	Angular frequency	rad/sec
W	Gas weight	lbs
$\dot{W}$	Gas weight flow rate	lbs/sec
A	Effective piston area	0.61 in.^{2}
dp	Piston diameter	15/16 in.
dr	Rod diameter	5/16 in.
dv	Valve orifice diameter	0.038 in.
Av	Valve orifice area	1.13×10^{-3} in.^{2}
C_m	Mass flow coefficient (helium)	14.26 $\sqrt{\text{in}}$/sec
C_d	Orifice discharge coefficient	0.65
$f\left(\frac{Pu}{P_d}\right)$	Unchoking factor	1.0 for $\frac{Pu}{P_d} \geq 0.58$
Ps	Supply pressure	2000 psi

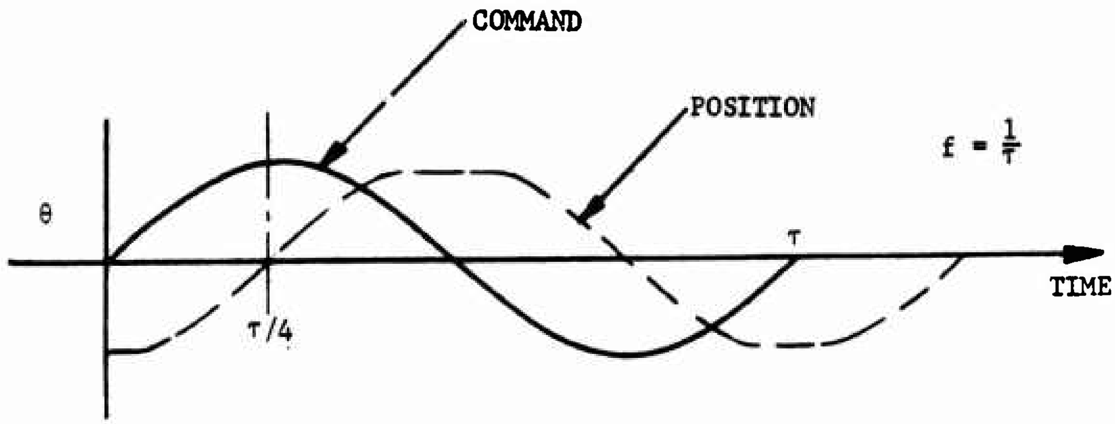


FIGURE 12. Command and Position Relationship.

output position to be only lagging the command by 90 degrees, the torque reversal must occur in a quarter of a cycle or in t/4 seconds (t = 1/ frequency).

The required torque rate ($\dot{\tau}$) is

$$\dot{\tau} = \frac{2\tau_F}{\frac{1}{4f}} \quad \text{or} \quad \dot{\tau} = 8\, f\, \tau_F$$

where

f = frequency, Hz

τ_F = coulomb friction torque, in-lb

For the piston actuator, the output torque is defined as

$$\tau = \Delta P A \ell$$

where

τ = applied torque (in-lb)

ΔP = differential pressure across piston (psi)

A = effective piston area (in.^{2}) = 0.61 in.^{2}

ℓ = moment arm = 2.40 in.

differentiating

$$\dot{\tau} = \Delta\dot{P}A\ell$$

for the closed center actuator

$$\Delta P \approx P_s - P$$

$$|\Delta\dot{P}| \approx \dot{P}$$

combining equations

$$\dot{P}A\ell = 8f\tau_F$$

$$\dot{P} = \frac{8f\tau_F}{A\ell}$$

from the ideal gas equation of state

$$\dot{P}V + \dot{V}P = \dot{W}RT$$

$$\dot{V} \to 0 \text{ for small amplitude motion}$$

$$\dot{P} = \frac{\dot{W}RT}{V}$$

combining the $\dot{P}$ equations

$$\frac{\dot{W}RT}{V} = \frac{8f\tau_F}{A\ell}$$

$V = \chi A$

χ = midstroke head clearance

A = effective area

The flow rate required to overcome friction at a certain frequency is

$$\dot{W}_F = \frac{8f\tau_F\,\chi}{\ell\, R\, T}$$

This equation defines the flow rate needed to follow a small amplitude sinusoidal command with 90 degree phase lag at a frequency, f.

For the worst case conditions

τ_F = 700 in-lb

T = 420°R (-40°F)

f = 15 Hz

ℓ = 2.4 in.

χ = 0.82 in.

Substituting:

$$\dot{W}_F = \frac{8\left(15\ \frac{\text{cycles}}{\text{sec}}\right)(700\ \text{in-lb})\ (0.82\ \text{in.})}{2.4\ \text{in.}\left(4635\ \frac{\text{in.}}{°\text{R}}\right)(420°\text{R})}$$

$\dot{W}_F$ = 0.0147 lbs/sec (helium)

Note that this factor is independent of actuator area. This is explained by the following example. Consider three piston actuators of different areas as shown in Figure 13 but all with the same stroke, moment arm, and coulomb friction load. For Figure 13a, if the required torque rate, $\dot{\tau}$, to move the output at a certain frequency $\dot{\tau} = \dot{P}A$, for small motions the flow rate required is

$$W = \frac{\dot{P}\,V}{RT} = \frac{\dot{\tau}}{A}\,\frac{V}{RT}$$

In Figure 13b, to maintain the same $\dot{\tau}$, the pressure rate must be doubled. But, since the volume is halved, the flow rate remains the same. Likewise, if the area is doubled (Figure 13c), the pressure rate is halved, but the volume is doubled. Hence, the flow rate again remains constant.

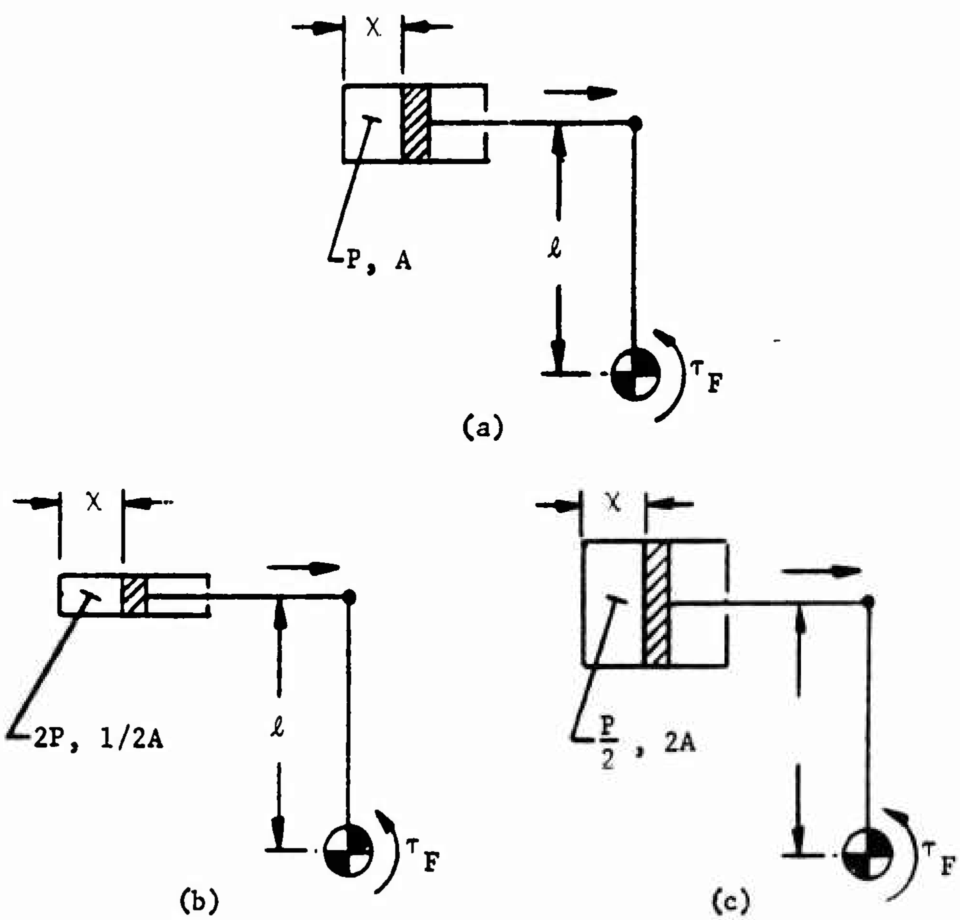


FIGURE 13. Actuator Stroke and Area.

Inertia Flow Rate. Similar logic can be used to determine the flow required for controlling the load inertia.

$$\dot{W}_J = \frac{32\,\pi^2\,J\,\theta_o\,f^3\,\chi}{\ell\,R\,T}$$

where θ_o is the peak sinusoidal position amplitude for a ±10 percent excursion

$$\theta_o = \frac{2^\circ}{57.3^\circ/\text{rad}} = 0.0349\ \text{rad}$$

Substituting:

$$\dot{W}_J = \frac{32\,\pi^2 \left(\frac{0.034\ \text{in-lb-sec}^2}{\text{rad}}\right) (0.0349\ \text{rad})\ (15\ \text{Hz/sec})^3\ (0.82\ \text{in.})}{(2.4\ \text{in.})\ (4635\ \text{in./}^\circ\text{R})\ (420^\circ\text{R})}$$

$\dot{W}_J = 2.22 \times 10^{-4}$ lbs/sec which is additive with the direction reversal flowrate, W_F.

Sinusoidal Velocity Flow Rate. The flow rate required while following a small amplitude sine wave is given by:

$$\dot{W}_{\dot{\theta}} = \frac{2\pi\,P_S\,A\,f\,\theta_o\,\ell}{R\,T}$$

The basis for selecting the actuator area will be discussed later.

For A = 0.61 in.^{2}, substituting

$$\dot{W}_{\dot{\theta}} = \frac{2\pi\ (2000\ \text{lbs/in.}^2)(0.61\ \text{in.}^2)(15\ \frac{\text{cy}}{\text{sec}})(0.0349\ \text{rad})(2.4\ \text{in.})}{(4635\ \text{in./}^\circ\text{R})(420^\circ\text{R})}$$

$$\dot{W}_{\dot{\theta}} = 4.95 \times 10^{-3}\ \text{lbs/sec} \cong 0.005\ \text{lb/sec}$$

Since direction reversal and maximum sinusoidal velocity occur 90 degrees apart when following a sine wave, the larger of the two terms govern the requirements.

The direction reversal terms are

$$\dot{W}_F + \dot{W}_J = (2.22 \times 10^{-4}) + (1.47 \times 10^{-2})\ \text{lbs/sec}$$

$$= 0.0149\ \text{lbs/sec}$$

The velocity term is

$$\dot{W}_{\dot{\theta}} = 0.005\ \text{lbs/sec}$$

It is obvious that the direction reversal terms govern ($\dot{W}$ = 0.015 lb/sec).

<u>Full Stroke Slew Rate - Volumetric Flow Rate</u>. The required maximum slew rate is 400 deg/sec or 7 rad/sec. The flow rate to meet a given slew rate is:

$$\dot{W}_{\dot{\theta}_M} = \frac{P_S\ A\ \dot{\theta}_m\ \ell}{R\ T}$$

Substituting:

$$\dot{W}_{\theta_M} = \frac{2000\ \frac{\text{lbs}}{\text{in.}^2}\ (0.61\ \text{in.}^2)(7\ \text{rad/sec})(2.4\ \text{in.})}{(4635\ \text{in./}^\circ\text{R})\ (420^\circ\text{R})}$$

$\dot{W}_{\theta_M}$ = 0.0105 lbs/sec which is less than the 0.015 lb/sec required for direction reversal.

The available pressurization rate in a hardover position is given by

$$\dot{P} = \frac{\dot{W}\ R\ T}{V}$$

where V is double the midstroke volume (total displacement) and $\dot{W}$ is maximum available flow rate.

$$\dot{P} = \frac{(0.015\ \text{lbs/sec})(4635\ \text{in./}^\circ\text{R})\ 420^\circ\text{R}}{(0.61\ \text{in.}^2)\ (1.64\ \text{in.})}$$

$$\dot{P} = 2.92 \times 10^4\ \text{psi/sec}$$

$$\dot{\tau} = \dot{P}\ A\ \ell = (2.92 \times 10^4\ \frac{\text{psi}}{\text{sec}})\ (0.61\ \text{in.}^2)\ (2.4\ \text{in.})$$

$$\dot{\tau} = 4.3 \times 10^4\ \text{in.-lbs/sec}$$

The time to generate 700 in-lbs is

$$\Delta t = \frac{\tau_F}{\dot{\tau}} = \frac{700\ \text{in-lb}}{4.3 \times 10^4\ \text{in-lb/sec}}$$

$$\Delta t = 16\ \text{milliseconds.}$$

Since the maximum available flow rate is greater than the minimum required (due to frequency response considerations) just to meet specified slew rate of 400 deg/sec, the slew rate for a hardover valve command is given by

$$\dot{\theta} = \frac{\dot{W}\ RT}{P_s\ A\ \ell} = \frac{(0.015\ \text{lbs/sec})\left(4635\ \frac{\text{in.}}{^{\circ}\text{R}}\right)(420^{\circ}\text{R})}{\left(2000\ \frac{\text{lbs}}{\text{in.}^2}\right)(0.61\ \text{in.}^2)(2.4\ \text{in.})}$$

$$\dot{\theta} = 9.97\ \text{rad/sec or } 571\ \text{deg/sec.}$$

The no load time from stop to stop is 40 deg/571 deg/sec, or 70 milliseconds. If the effect of friction on slew time is considered, then the total slew time for 40 degrees is 0.016 + 0.070 = 0.086 sec, for a slew rate of 40/0.086 = 465 deg/sec.

Notice that the assumed pressure rate is dependent only on the venting cylinder chamber. This is not true in reality, since gas must enter the pressurized cylinder chamber to make up for volumetric flow used in slewing. Since this flow rate (and the cylinder pressure) depend on the slewing velocity, the problem becomes closed loop and must be solved by computer simulation to include this term.

Valve Orifice Sizing

The calculations above have computed the maximum instantaneous flow rate required to achieve a 15 Hz bandwidth at -40°F. This flow rate, 0.015 lb/sec, defines the valve orifice size. It is assumed the servo control electronics have been adjusted so that the valve is achieving maximum flow as demanded by the servo.

The valve orifice diameter may be calculated from the flow equation

$$\dot{W} = \frac{C_d\ Cm\ A_v\ P_s\ f(Pu/Pd)}{\sqrt{R\ T}}$$

The orifice area is given by

$$Av = \frac{\pi d_v^2}{4}$$

and since the valve orifice is venting a pressurized cylinder chamber to atmosphere, choked flow nearly always occurs so that f(Pu/Pd) = 1.0.

$$d_v^2 = \frac{4\ \dot{W}\sqrt{R\ T}}{C_d\ C_m\ PU\ \pi}$$

$$d_v^2 = \frac{4\ (0.015\ \text{lbs/sec})\sqrt{(4635\ \text{in./}^{\circ}\text{R})(420^{\circ}\text{R})}}{(0.65)(14.26)\sqrt{\text{in.}}/\text{sec}\ (2000\ \text{lb/in.}^2)\ (\pi)}$$

$$d_v^2 = 1.44 \times 10^{-3}\ \text{in.}^2$$

$$d_v = 0.038\ \text{in.}$$

The maximum size of the valve orifices are limited by the magnet and spring force available to overcome the P x A force created by the orifice area and the supply pressure. The flapper valve in this configuration has been found to perform best when the vent and inlet orifice areas are the same.

Piston Area Determination

Piston area is determined largely by the need to accommodate a widely varying friction load. Of course, the minimum stall force of the actuator must be sufficient to overcome the largest value of coulomb friction. Excess force capability over and above this value is dictated by servo stability.

From results obtained in a feasibility study simulation, it was found that stall torque to coulomb friction torque ratio should be 3.7:1 to provide sufficient force margin to be insensitive to friction load variations. This provides high load response without incurring low load instability.

Since

$$\frac{\tau_{stall}}{\tau_F} = 3.7$$

If τ_F = 700 in-lbs, then τ_{stall} = 2590 lbs. In order to keep the piston size relatively small, it is desirable to use a high system supply pressure. It is also necessary to minimize the piston diameter to permit packaging the actuator in the annular envelope available. With P_s = 2000 psi and a moment arm of 2.4 in., the required area is

$$A = \frac{\tau}{P_s \ell} = \frac{2590 \text{ in-lbs}}{2000 \frac{\text{lbs}}{\text{in.}^2} (2.4 \text{ in.})} = 0.54 \text{ in.}^2$$

From mechanical considerations it is desirable to have a 5/16-inch diameter piston rod. Therefore the piston size is calculated as

$$A = \frac{\pi (d_p^2 - d_r^2)}{4}$$

$$d_p^2 = \frac{4A}{\pi} + d_r^2$$

$$d_p^2 = \frac{4 (0.54)}{\pi} + (0.3125)^2$$

$$d_p = 0.886 \text{ in.}$$

The closest convenient diameter that will yield at least as much area as a 0.886 diameter piston is d_p = 15/16 in. diameter so that the effective area of the piston is

$$A_p = \frac{\pi (0.9375^2 - 0.3125^2)}{4} = 0.61 \text{ in.}^2.$$

This diameter permits packaging in the envelope.

CONTROL SYSTEM

The basic operation and block diagram for the Control System has been shown in Figure 8. The circuit schematic that mechanizes the block diagram is shown in Figure 10.

A single integrated circuit generates the 100 Hz carrier triangle wave used by both the PDM modulators. One hundred Hz has been found to be the highest PDM frequency that is practical for the 5/16-inch diameter flapper valves. The valve coils are designed so that 28 Vdc power can be used as the input voltage for the driver stage; ±12 Vdc is required to power the integrated circuits and feedback pot.

Each valve coil has a dc resistance of 23 Ω. With a supply voltage of 28 Vdc, the total power dissipated per actuator is 34 watts when a valve is hardover. No external power resistors are required. For missile battery sizing, the duty cycle required should be taken into account since, when the servo error signal goes to zero, no dc power is used except that required to maintain ±12 Vdc across the integrated circuits.

There are three loop gain adjustments. Each modulator has its own gain for equalizing differences between valves, the third gain control operates directly on the error signal and allows setting the overall gain with one control.

The "cross-over" adjustments are essentially dc bias terms that are added to the modulator input. Since the valves normally require 20 to 25 percent PDM command to begin pressure modulation, these bias controls can be used for varying the system pressure deadband. To maintain closed center operation, there must be some finite deadband. In practice, it has been found that a 5 to 10 percent overlap produces the best results; the deadband is at a virtual minimum.

One of the primary control considerations is to maintain a high bandwidth, high gain system while keeping a good damping ratio, regardless of a load that can vary between 200 and 700 in-lbs. This problem was addressed by computer simulation. The simplest and most direct way found was to size the actuator so that the load appeared to be a relatively insignificant percentage of the total stall force capability. Simulations indicated a ratio of stall force to load force of about 3.7:1 produced good results. Electronic compensation aids in stabilizing the servo.

An electronic lead-lag network of the form

$$10\left(\frac{S + 200}{S + 2000}\right)$$

is used. The equalization is mechanized in state-variable form (analog computer style) to simplify experimental location of the poles and zeros.

TEST RIG DESIGN

The Thiokol trapped ball nozzle assembly was not available for this program, and it was necessary to provide a test rig with similar friction, inertia, and kinematics. Figure 14 shows the servo actuator mounted in the Aeronutronic load fixture. A rigid bracket containing a self-aligning bearing (NMB ABYT4) supports the fixed end of the actuator. The output rod end is attached to a 2.40 inch radius crank arm, simulating the nozzle attach point with an 8.75 inch center distance. The crank arm is welded to a 1.00 inch diameter shaft, and is straddle mounted between a pair of pillow block bearings. Cantilevered from one end of the shaft is a 6.00 inch diameter Tol-O-Matic disc brake. Two disc brake caliper assemblies are mounted on the test stand structure and grip the brake disc at two diametrically opposite points. The caliper assemblies are pressurized with nitrogen to establish the desired friction torque levels. A smaller disc is cantilevered from the opposite end of the crank arm shaft. Its purpose is to provide additional moment of inertia to the load assembly. This disc is sized to bring the total moment of inertia of the crank, shaft, and disc assembly up to the specified value of 14 $in.^2$-lb or 0.0363 in-lb-sec^2/rad. The moment of inertia was confirmed experimentally by the torsional pendulum technique and the final dimensions of the add-on inertia disc were selected to achieve the required value. The test stand friction torque was calibrated experimentally by hanging known weights on the crank arm and adjusting the brake pressure to just allow slippage. Since this technique basically determined the static friction of the brake assembly, the dynamic friction was obtained during actuator testing by measuring the required P x A forces to maintain constant slew rates. The high load condition of 700 in-lb torque required a brake pressure of 275 psig, while 60 psig provided the 200 in-lb low load torque.

The test setup also included a high pressure gas supply system made up of typical missile system components. It is seen in the photo of Figure 15. The gas supply system schematic is shown in Figure 16. This system utilizes many missile-type flight weight components, combined with necessary instrumentation and lab control elements. Two 71 $in.^3$ gas storage bottles are manifolded together to form the primary storage volume. These are bottles manufactured by Apco for use on the Maverick Missile. Their hermetically sealed fill and run components have been removed to facilitate making repeated tests in the lab. They are filled through a solenoid valve from the facility high pressure (6600 psi) helium supply. The bottles are connected to a solenoid run valve and then to an Altair 215 R 7000 flightweight pressure regulator. The regulator is rated up to 10,000 psi inlet and regulates the downstream pressure to 2000 psi. A 2500 psi relief valve is installed in a tee on the

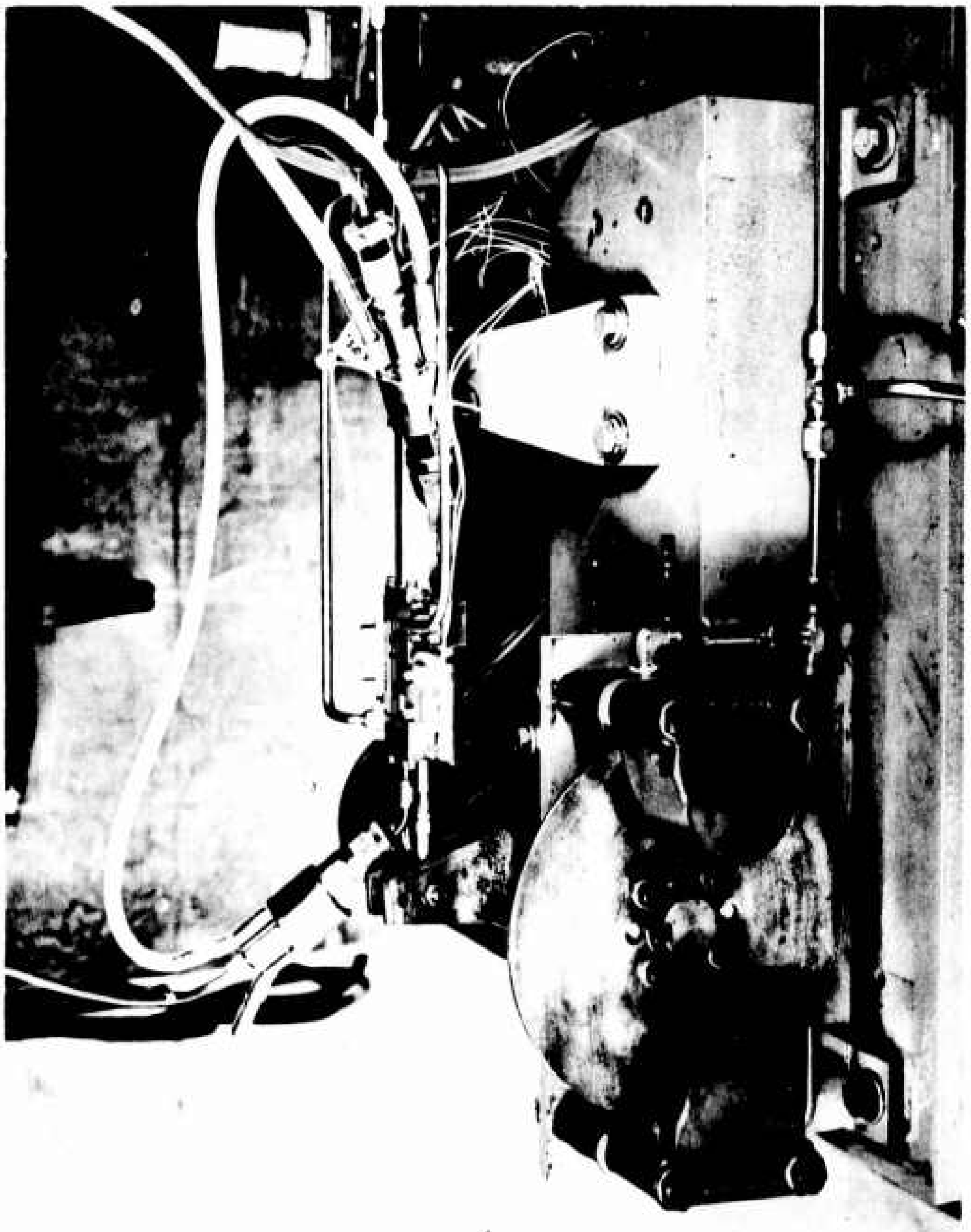


FIGURE 14. Actuator Mounted on Load Fixture.

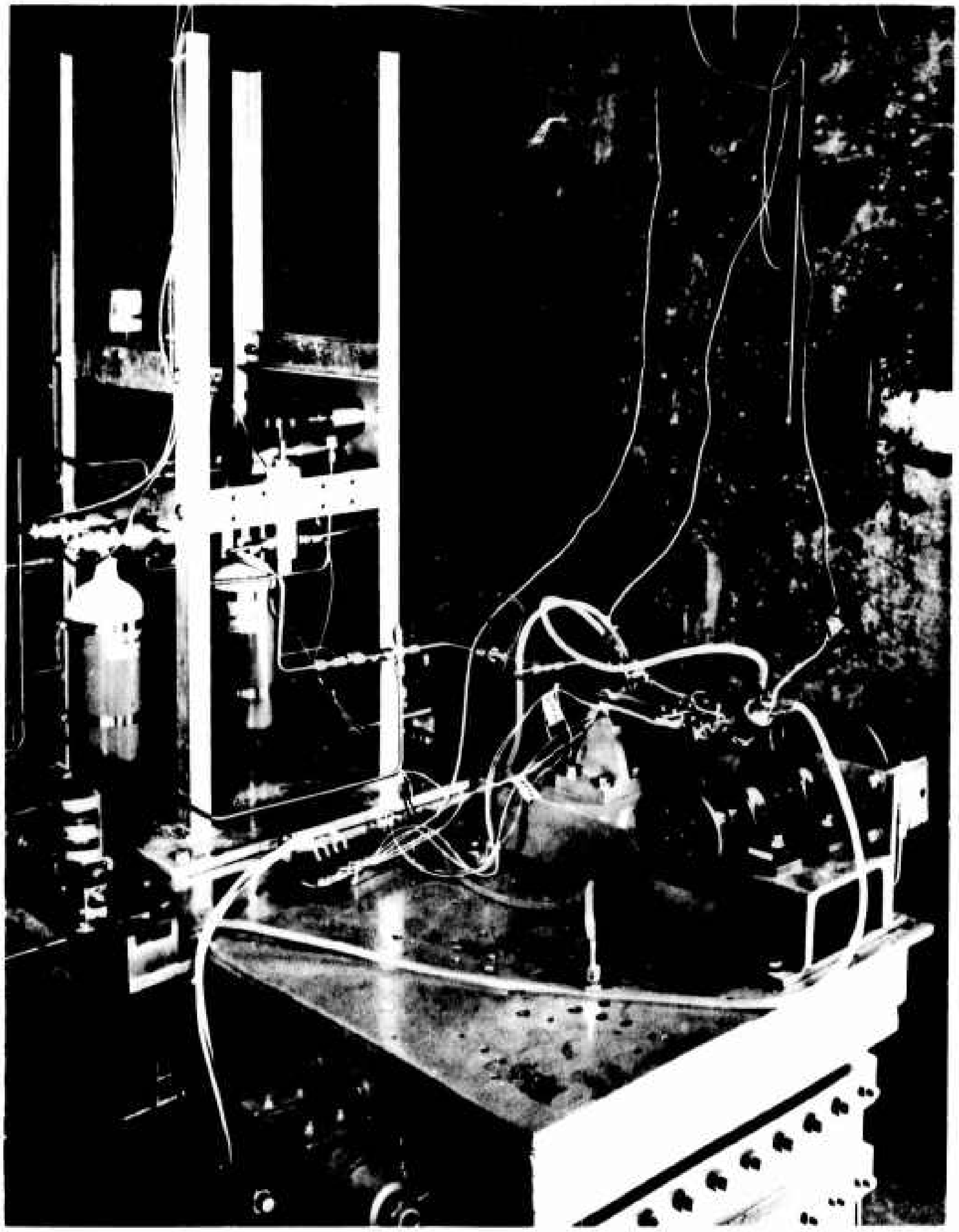


FIGURE 15. Gas Supply System.

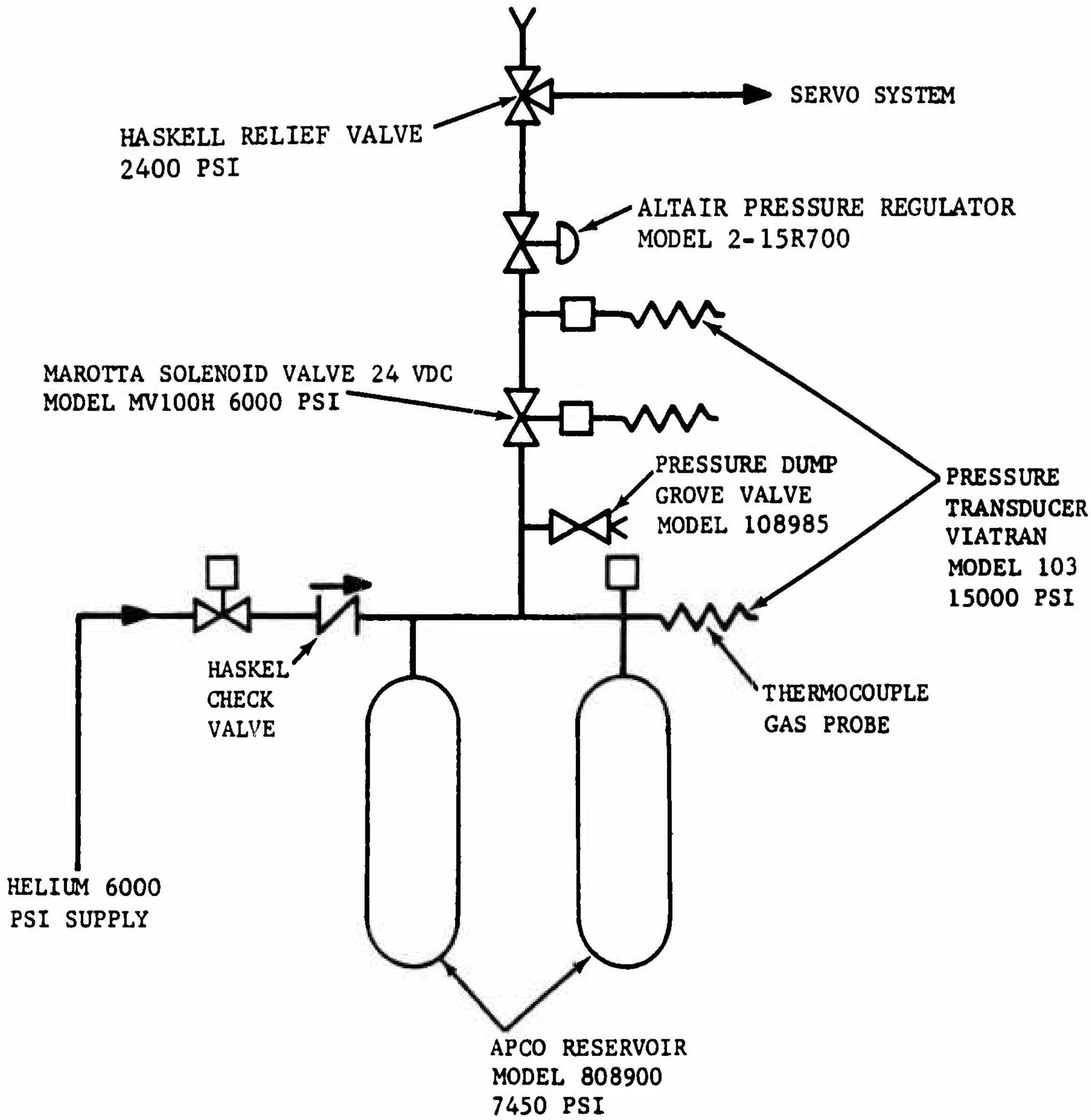


FIGURE 16. Cold Gas Servo Gas Supply Breadboard.

line between the regulator and the actuator inlet fitting. Its purpose is to prevent excessive downstream pressures due to regulator leakage when the closed center actuator valves are shut off. Actuator flow measurements are taken from this system by monitoring initial and final bottle pressure after allowing the system to temperature stabilize.

TEST RESULTS

The servo actuator performance was obtained using the friction-inertia test rig described earlier. Most tests were duplicated using both helium and nitrogen as the working fluids. All tests were run at a nominal gas supply temperature of 60°F, and a regulated servo inlet pressure of 2000 psig. The valve PDM frequency was maintained at 100 Hertz. Two levels of friction torque were established, high load (700 in-lb) and low load (200 in-lb). The test rig moment of inertia was 14 $lb\text{-}in^2$ or 0.0363 $in\text{-}lb\text{-}sec^2/rad$. The crank arm radius of 2.40 inches resulted in a ±0.82 inch stroke at ±20 degree output angle.

The electronic controller gain settings were optimized for helium operation and the same control settings were used for both the helium and nitrogen tests. Tests conducted included:

1. High and low load frequency response (Bode plots and phase lag) at ±2 degree amplitude commands and frequencies ranging from 0.5 Hz to 50 Hz.

2. Differential pressure versus stroke at low slew rates.

3. Slew rate and gas consumption tests for a series of 10 second runs on the 145 in^3 gas supply bottle system. These tests included high and low loads, sine and square wave commands, amplitudes of ±2, ±5, ±10, ±15, and ±20 degrees, and frequencies of 1, 5, 10, and 15 Hertz. Command and output position were recorded on oscillograph traces along with the piston differential pressure. The bottle supply pressures before and after each run were recorded after temperatures were stabilized to permit calculating the flow rate.

4. Valve component response tests using a fixed cylinder volume. Valve output (cylinder pressure) versus % PDM command was presented on a X-Y plotter.

5. Acceptance tests according to the acceptance test plan.

HELIUM PERFORMANCE

Figure 2 shows a typical Bode plot under high load conditions, and Figure 17 shows the low load frequency response and phase lag. Figure 18 shows plots of calculated flow rates under high loads for both sinusoidal

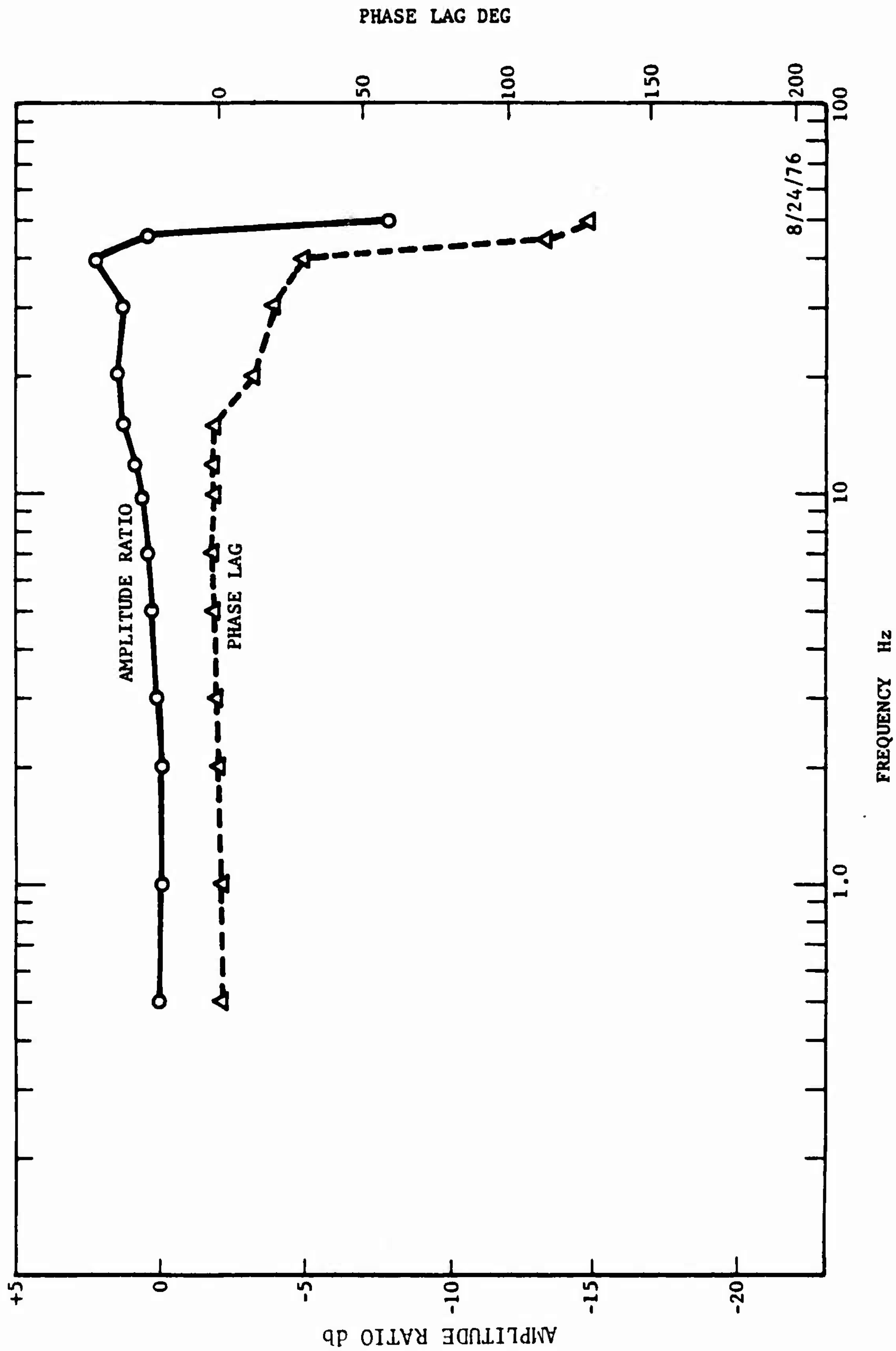


FIGURE 17. NWC Actuator Frequency Response on Helium (Gain 0.58°/100%) - Low Load.

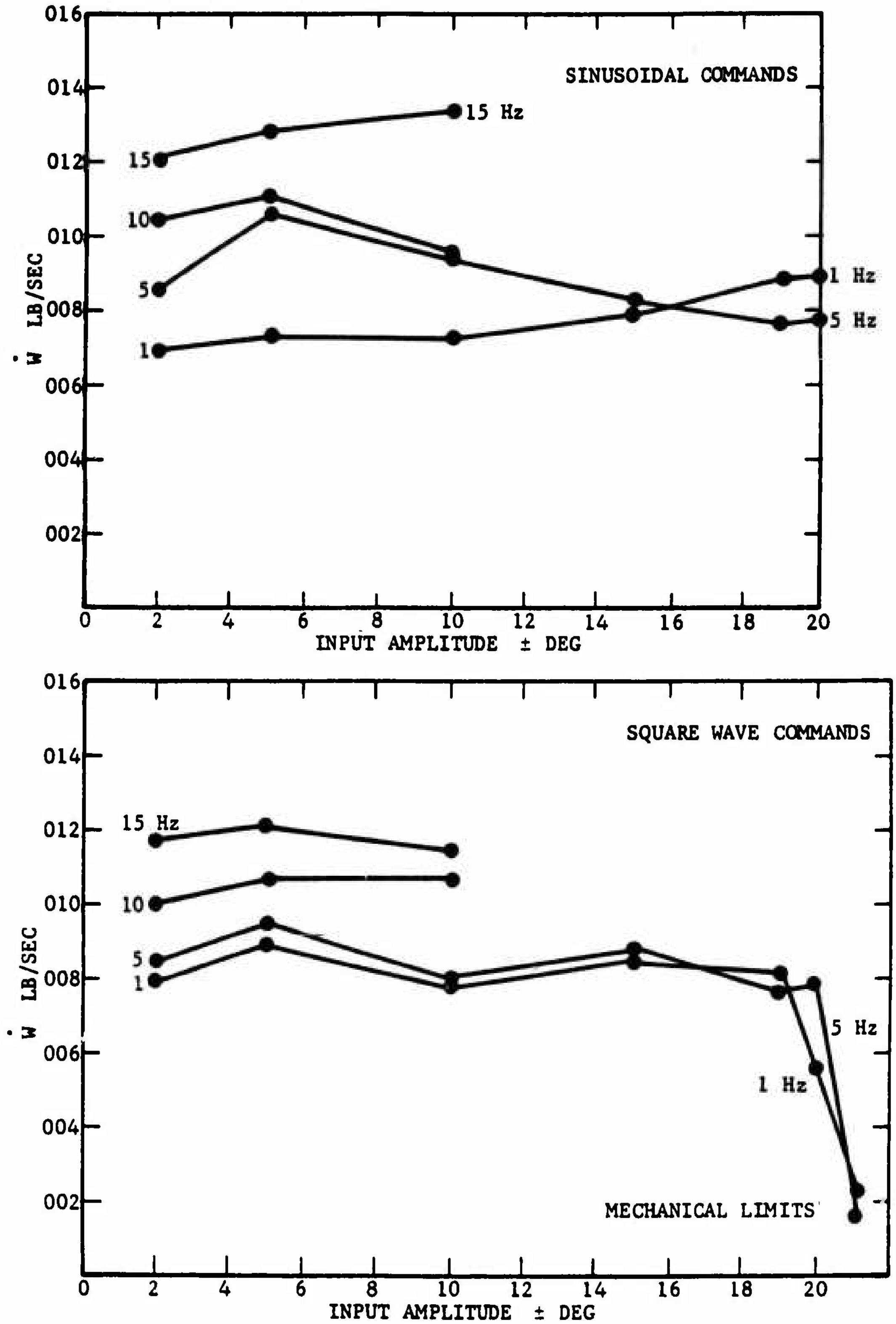


FIGURE 18. NWC Actuator Flow Rate on Helium - High Load.

and square wave commands. It is seen that flow rate is primarily a function of frequency and is relatively insensitive to command amplitude. The flow rate at ±2°, 15 Hz sine or square wave commands is about 0.012 lb/sec at high load and 0.014 lb/sec at low load. Figure 19 shows a similar plot of flow rates for low load conditions.

Figures 20 through 43 shows a series of typical oscillograph traces for a range of commands. The actuator differential pressure traces are shown below the command and position traces. The pressure trends shown are typical, but the accuracy of the absolute magnitude of pressure is questionable due to a possible error in recording technique. Average slew rates can be obtained from the square wave command data. Table 4 summarizes the slew rates determined from the high and low load helium tests.

Helium performance tests were also run using large amplitude triangle wave commands, starting with low frequencies, to determine the actuator pressure differential required to slew the load fixture at low slew rates. Higher frequencies commanded higher slew rates, permitting an investigation of the dynamic load characteristics to see if there was any viscous damping content in the applied load.

NITROGEN PERFORMANCE

Figures 44 and 45 show typical Bode plots of frequency response and phase lag for the actuator under high and low load conditions. The gain settings for the controller are those which gave optimum helium performance. The required average flow rates operating with nitrogen for a range of commands were obtained by the same techniques used with helium. Figures 46 and 47 present the nitrogen flow rate data for high and low loads, sine and square wave commands, as functions of frequency and command amplitude. Table 5 summarizes the slew rates obtained from the nitrogen testing.

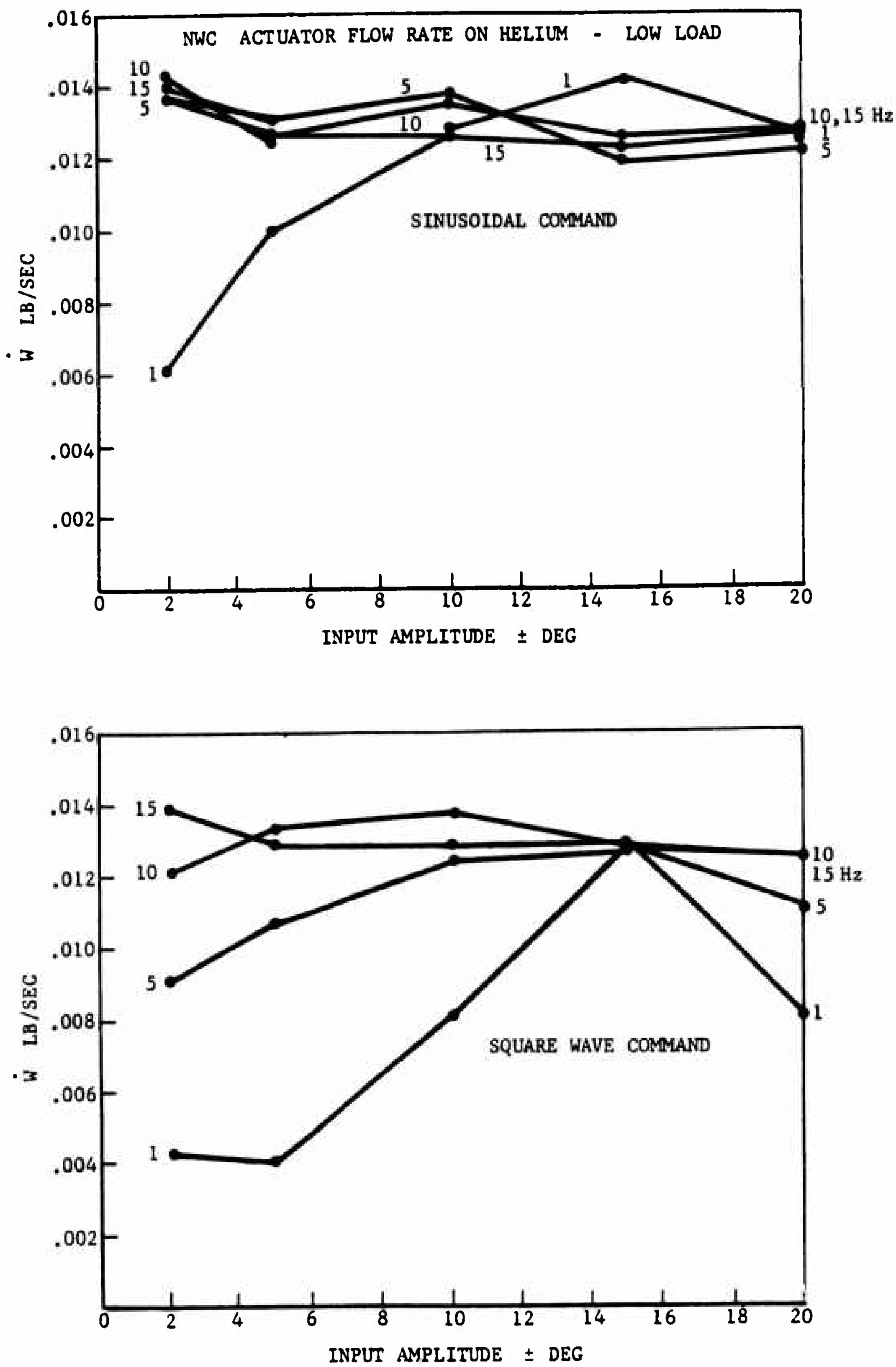


FIGURE 19. NWC Actuator Flow Rate on Helium - Low Load.

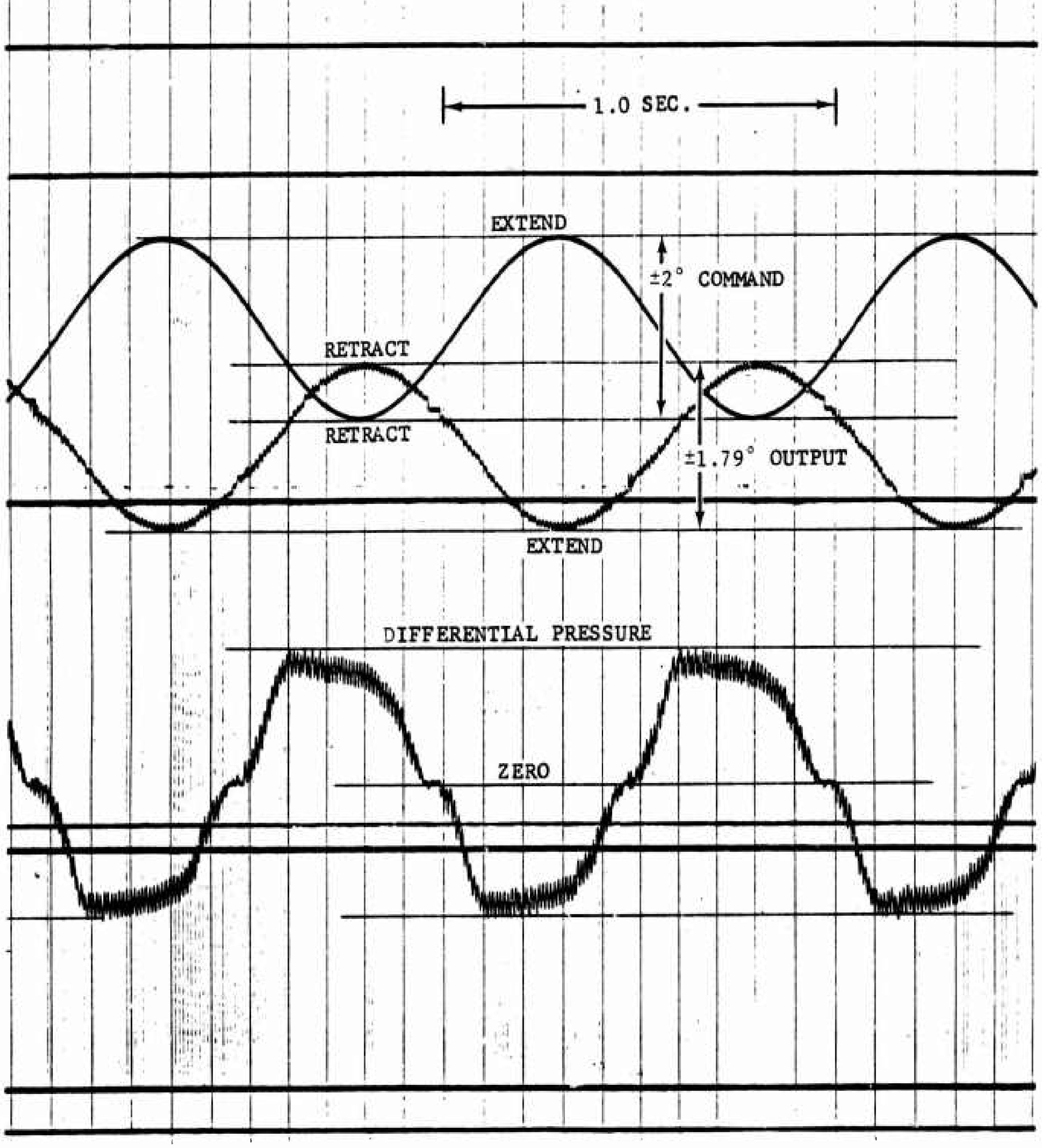


FIGURE 20. High Load Helium Performance - ±2°, 1 Hz Sine Wave Commands.

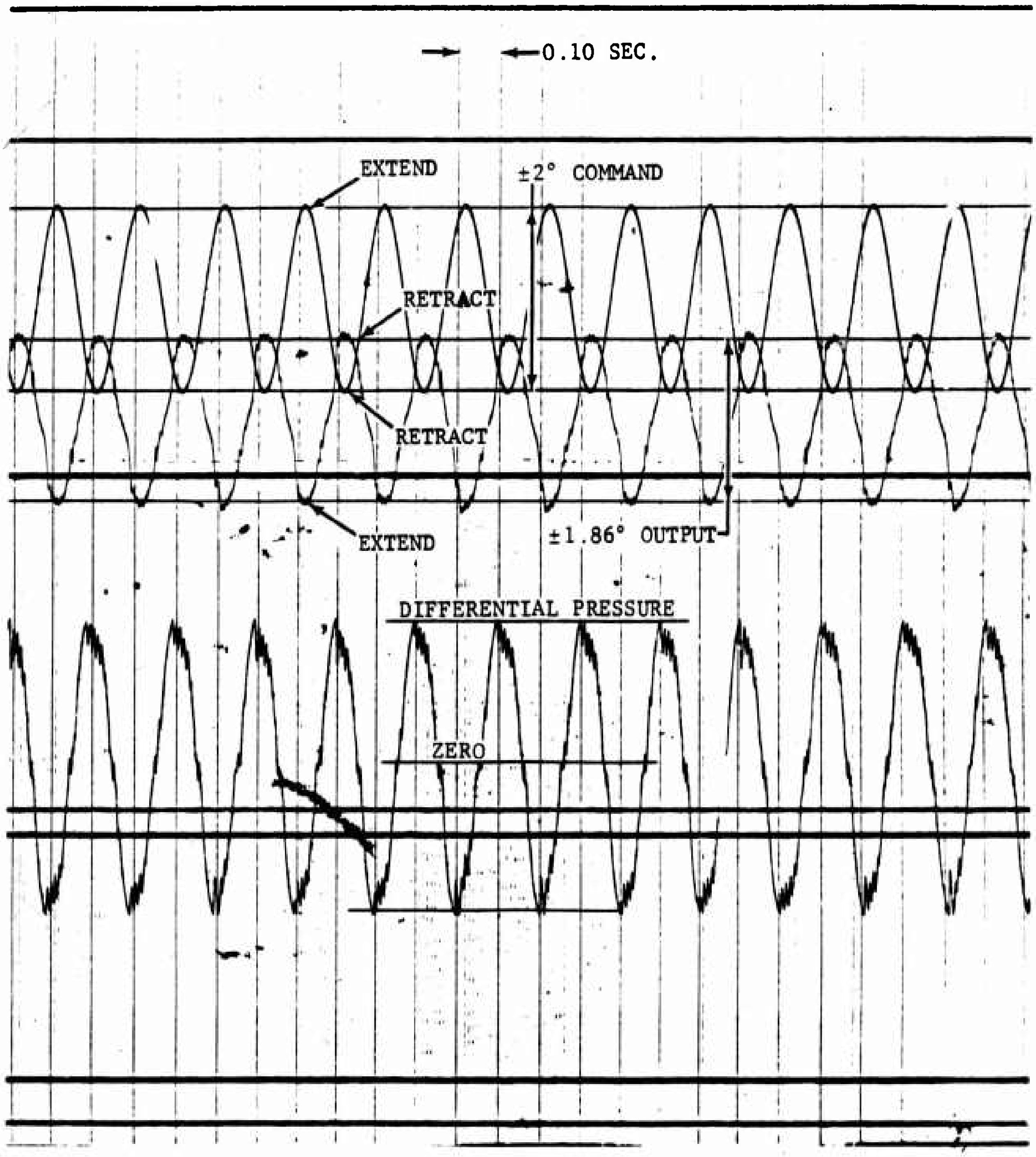


FIGURE 21. High Load Helium Performance - ±2°, 5 Hz Sine Wave Commands.

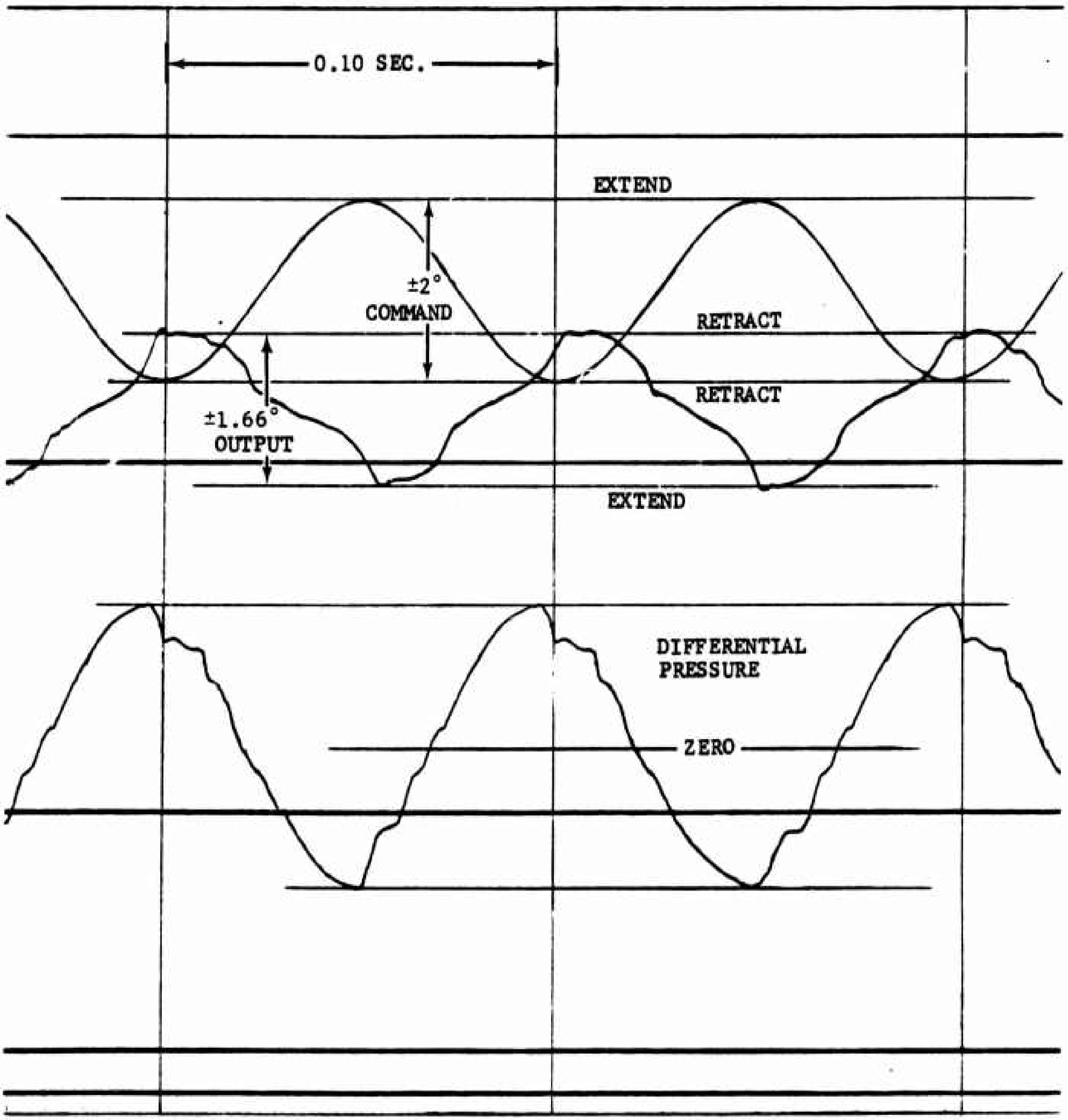


FIGURE 22. High Load Helium Performance - ±2°, 10 Hz Sine Wave Commands.

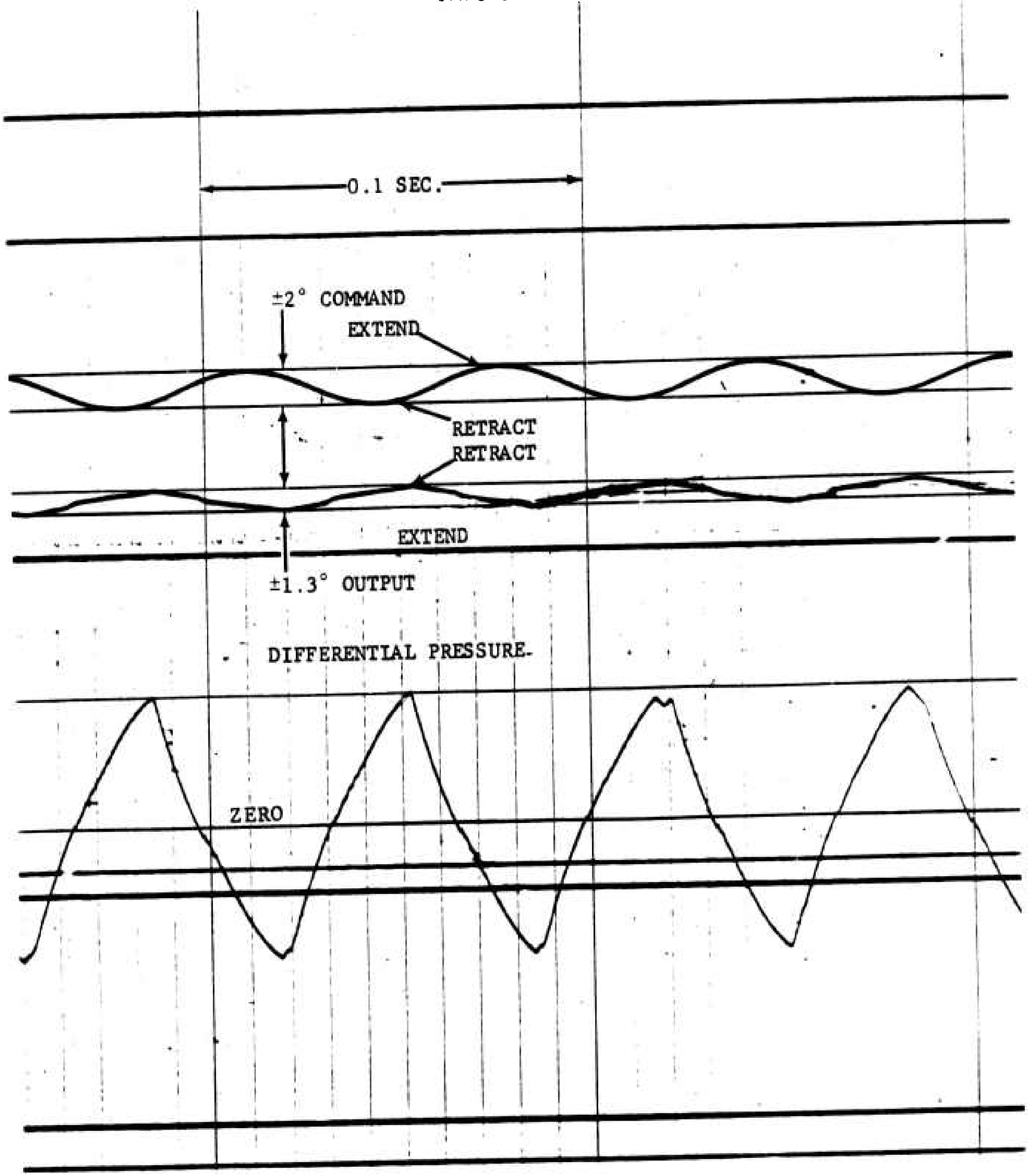


FIGURE 23. High Load Helium Performance - ±2°, 15 Hz Sine Wave Commands.

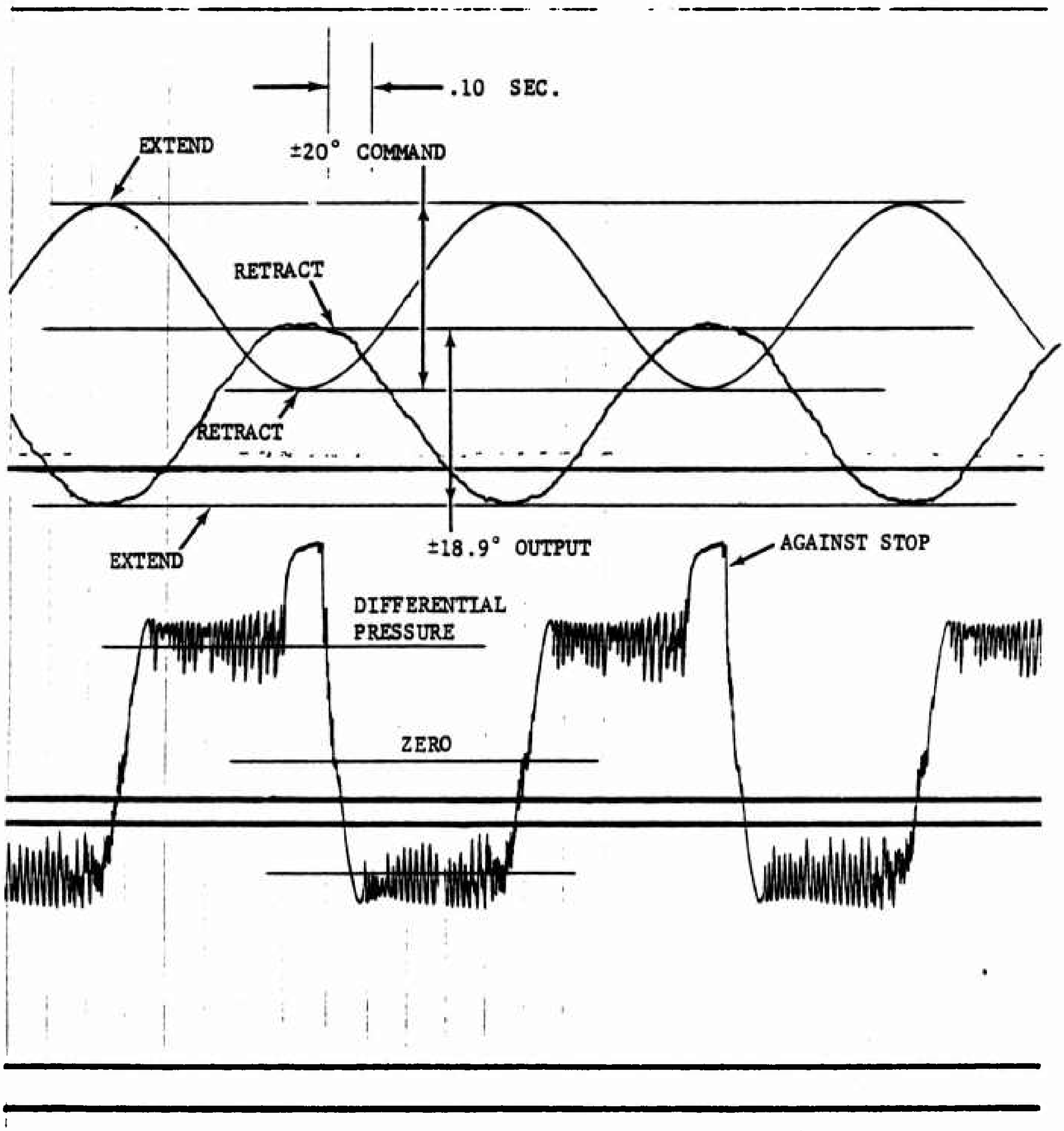


FIGURE 24. High Load Helium Performance - ±20°, 1 Hz Sine Wave Commands.

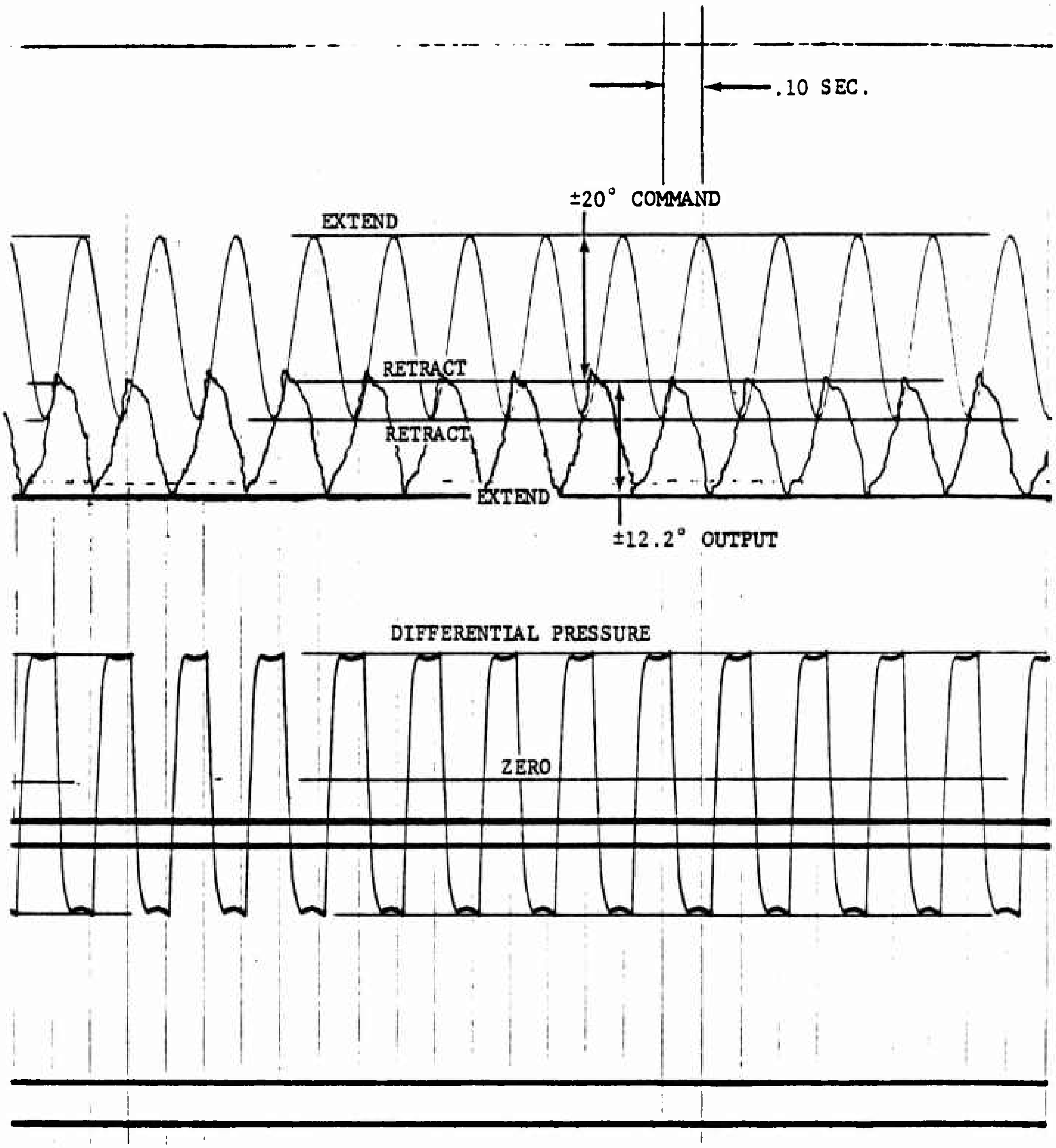


FIGURE 25. High Load Helium Performance - ±20°, 5 Hz Sine Wave Commands.

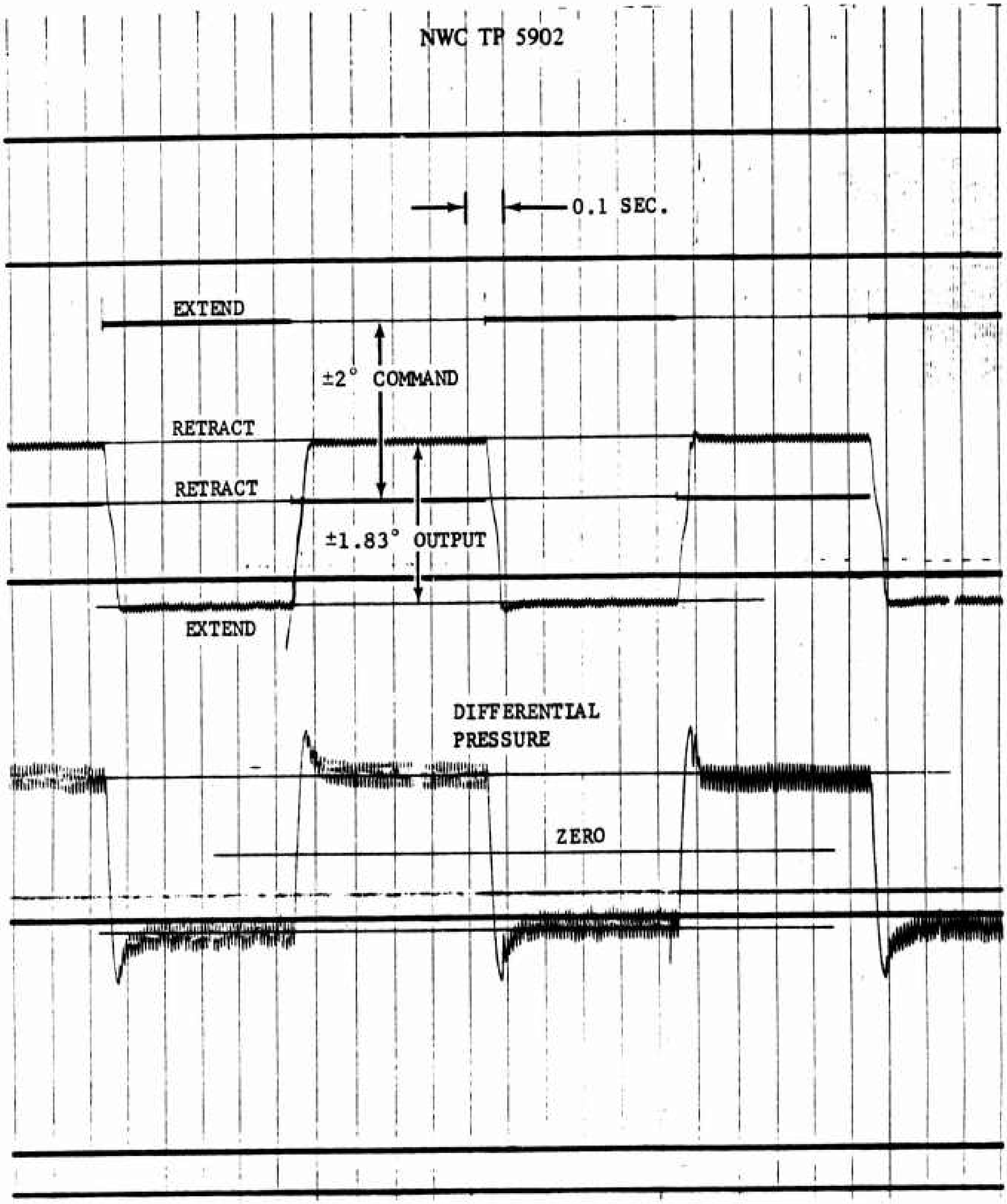


FIGURE 26. High Load Helium Performance - ±2°, 1 Hz Square Wave Commands.

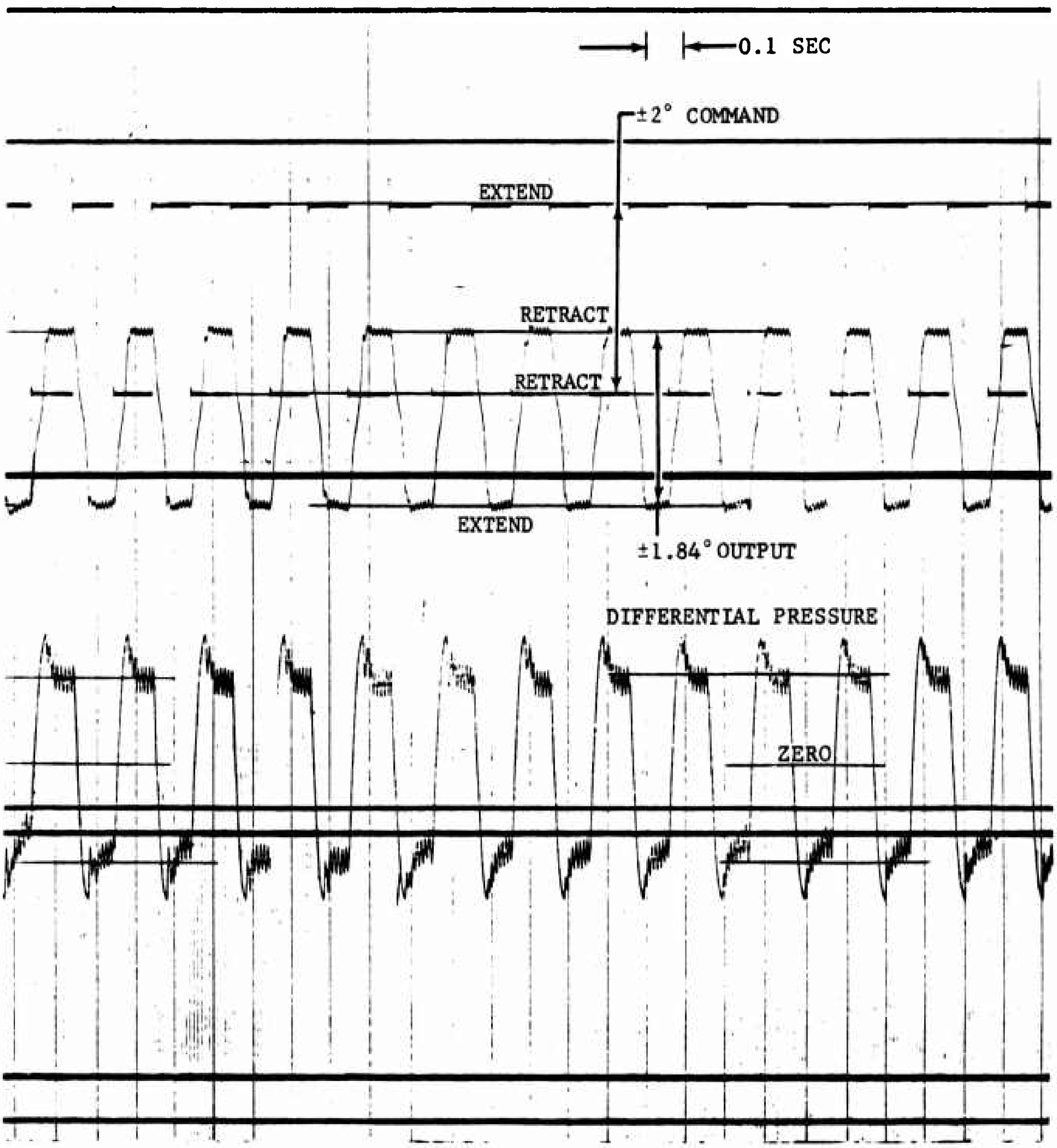


FIGURE 27. High Load Helium Performance - ±2°, 5 Hz Square Wave Commands.

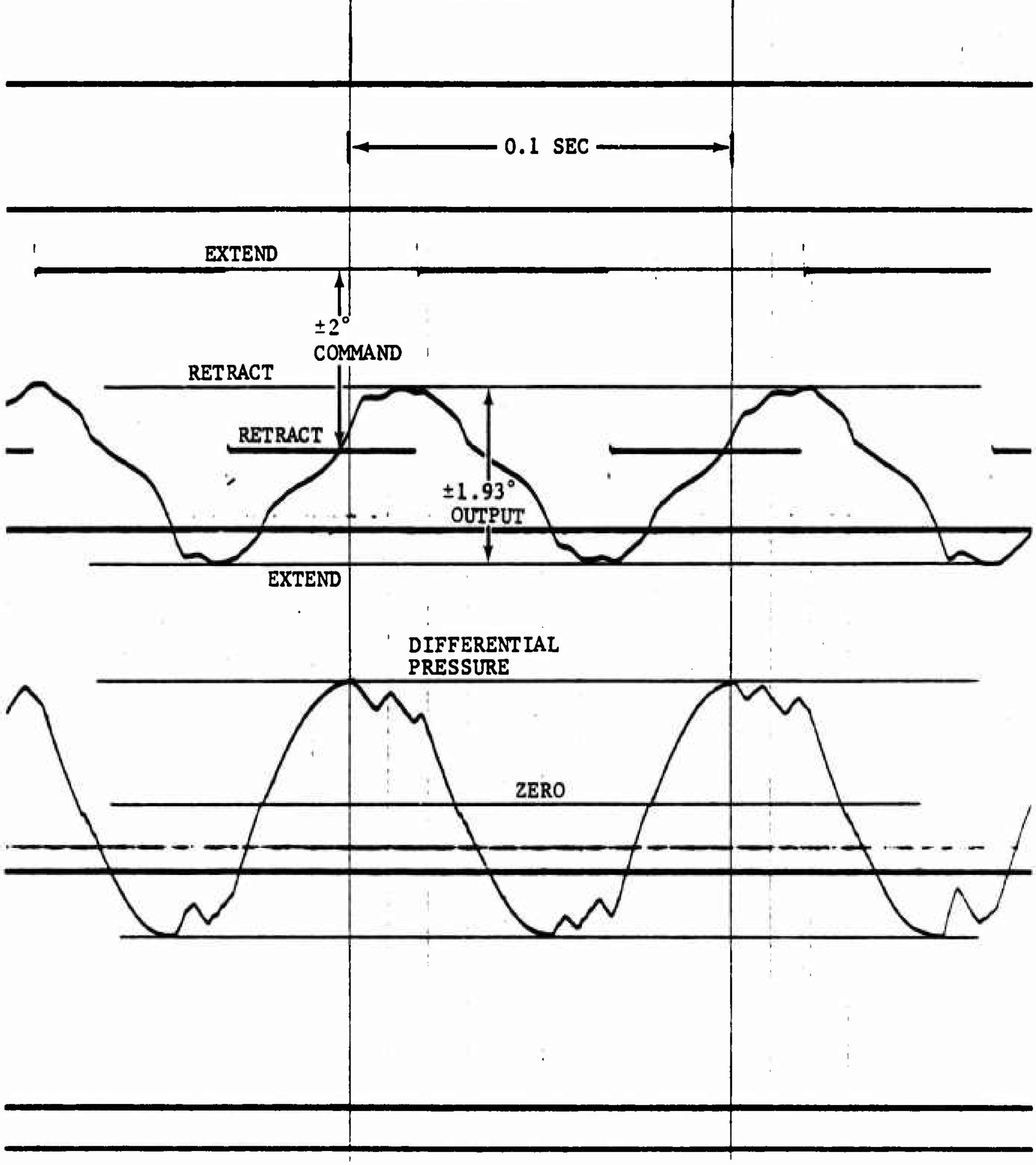


FIGURE 28. High Load Helium Performance - ±2°, 10 Hz Square Wave Commands.

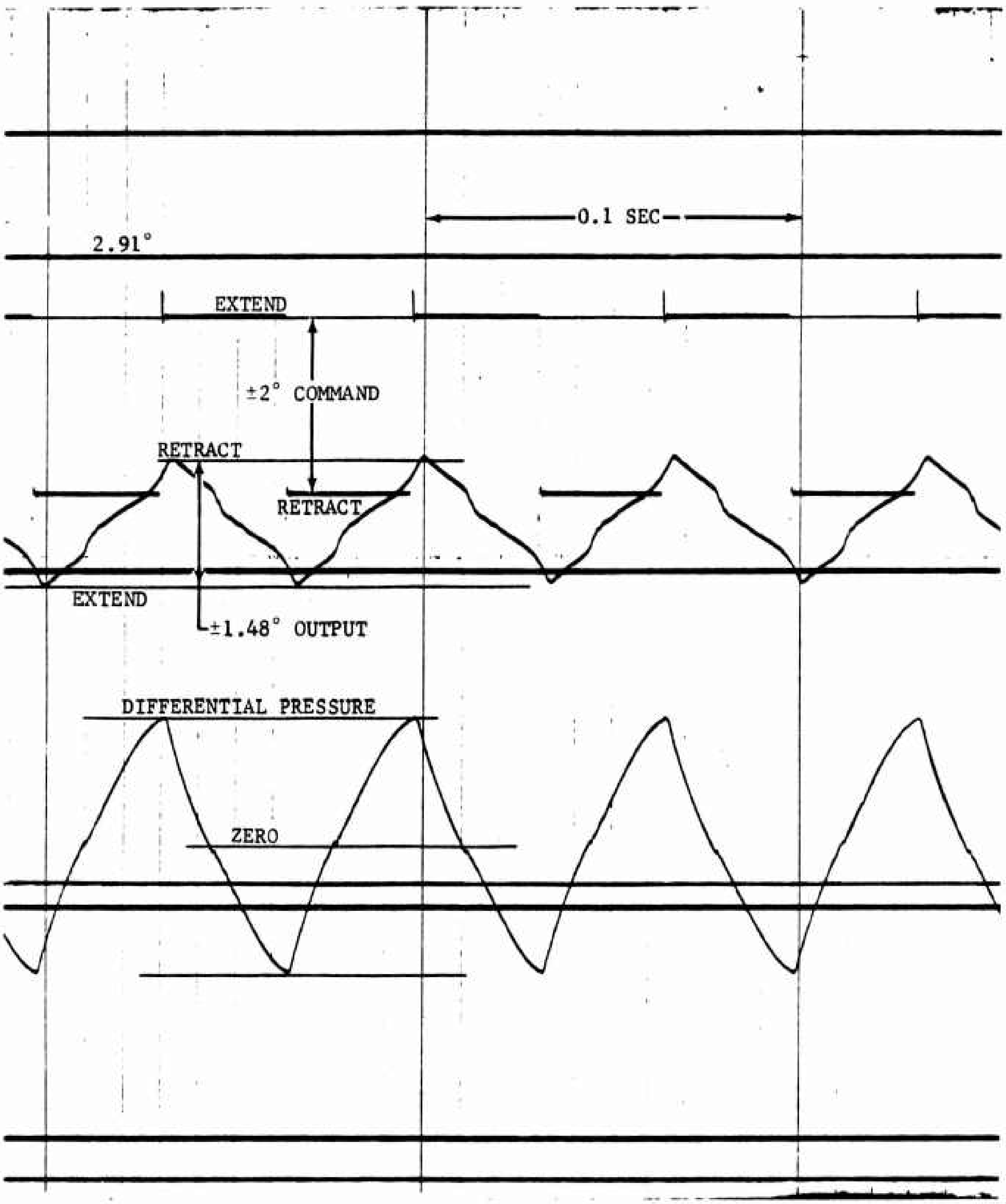


FIGURE 29. High Load Helium Performance - ±2°, 15 Hz Square Wave Commands.

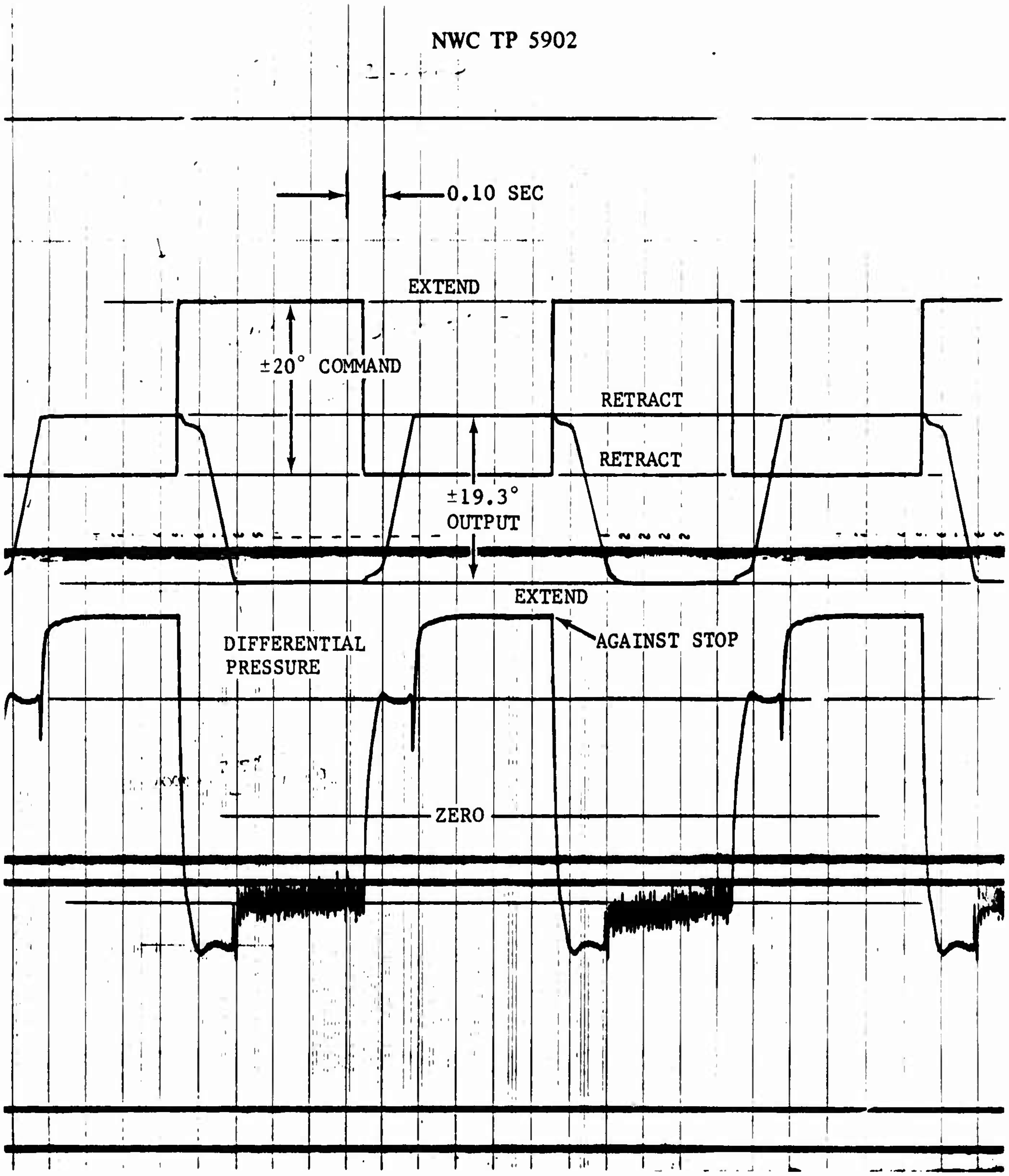


FIGURE 30. High Load Helium Performance - ±20°, 1 Hz Square Wave Commands.

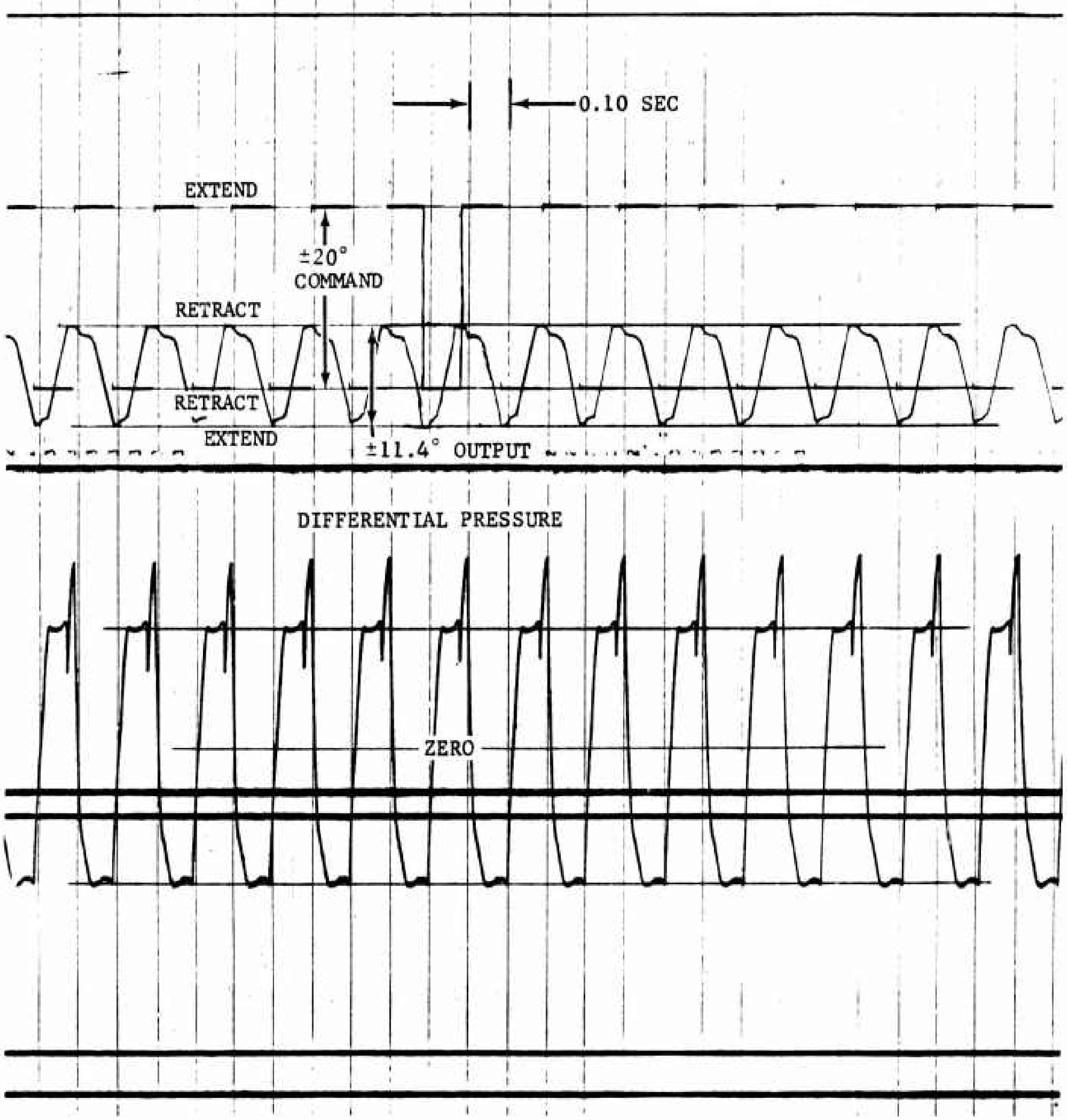


FIGURE 31. High Load Helium Performance - ±20°, 5 Hz Square Wave Commands.

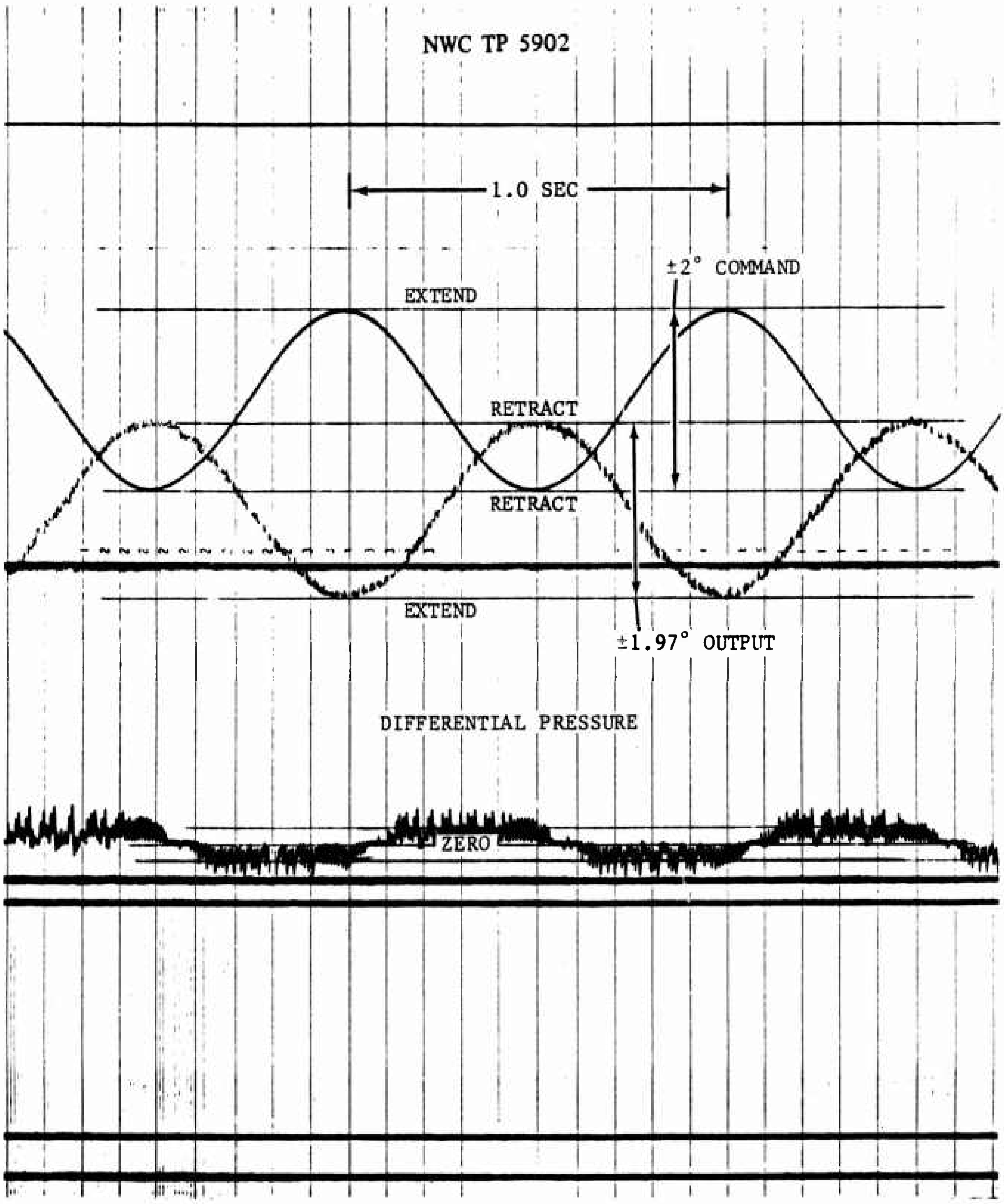


FIGURE 32. Low Load Helium Performance - ±2°, 1 Hz Sine Wave Commands.

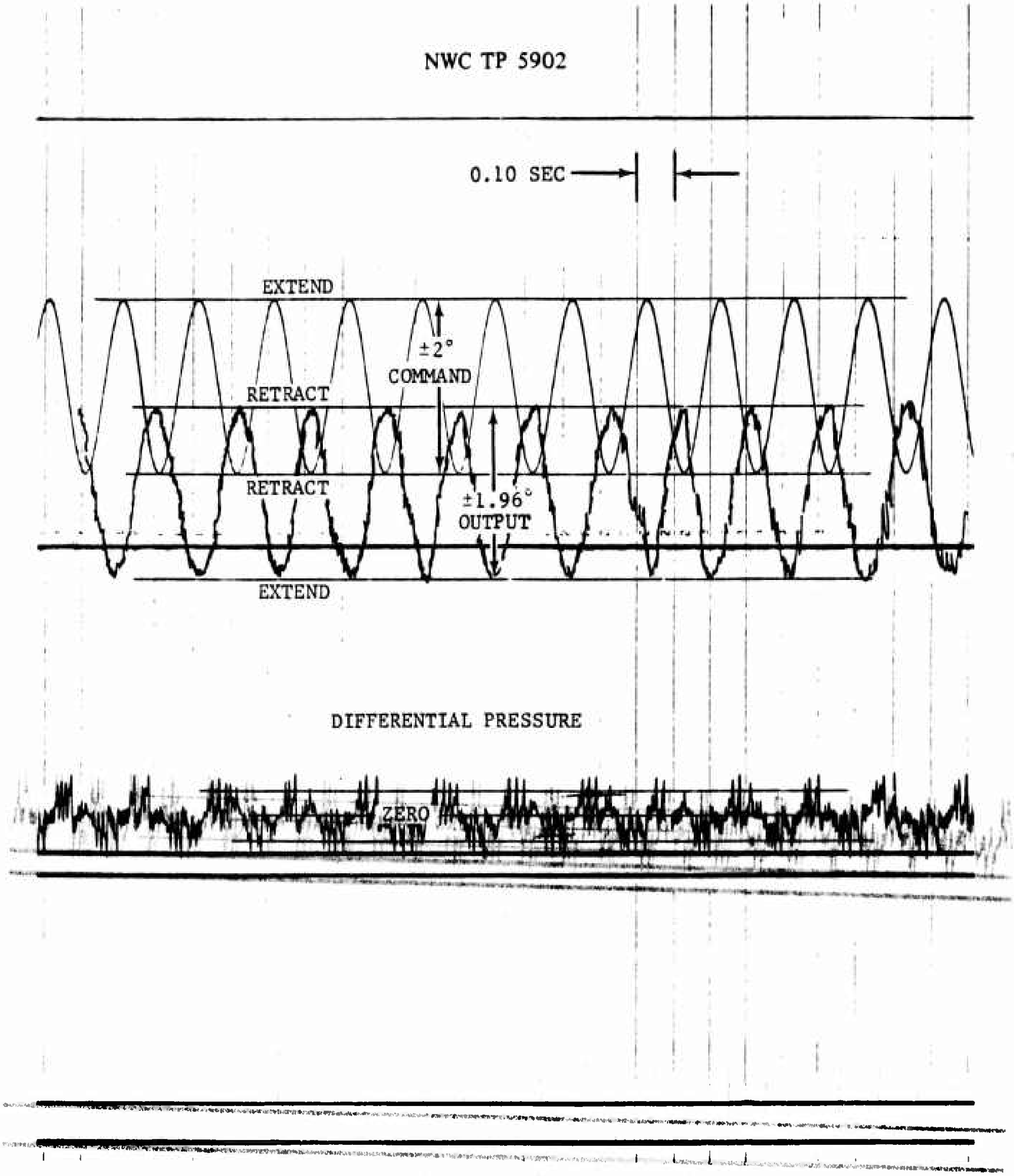


FIGURE 33. Low Load Helium Performance - ±2°, 5 Hz Sine Wave Commands.

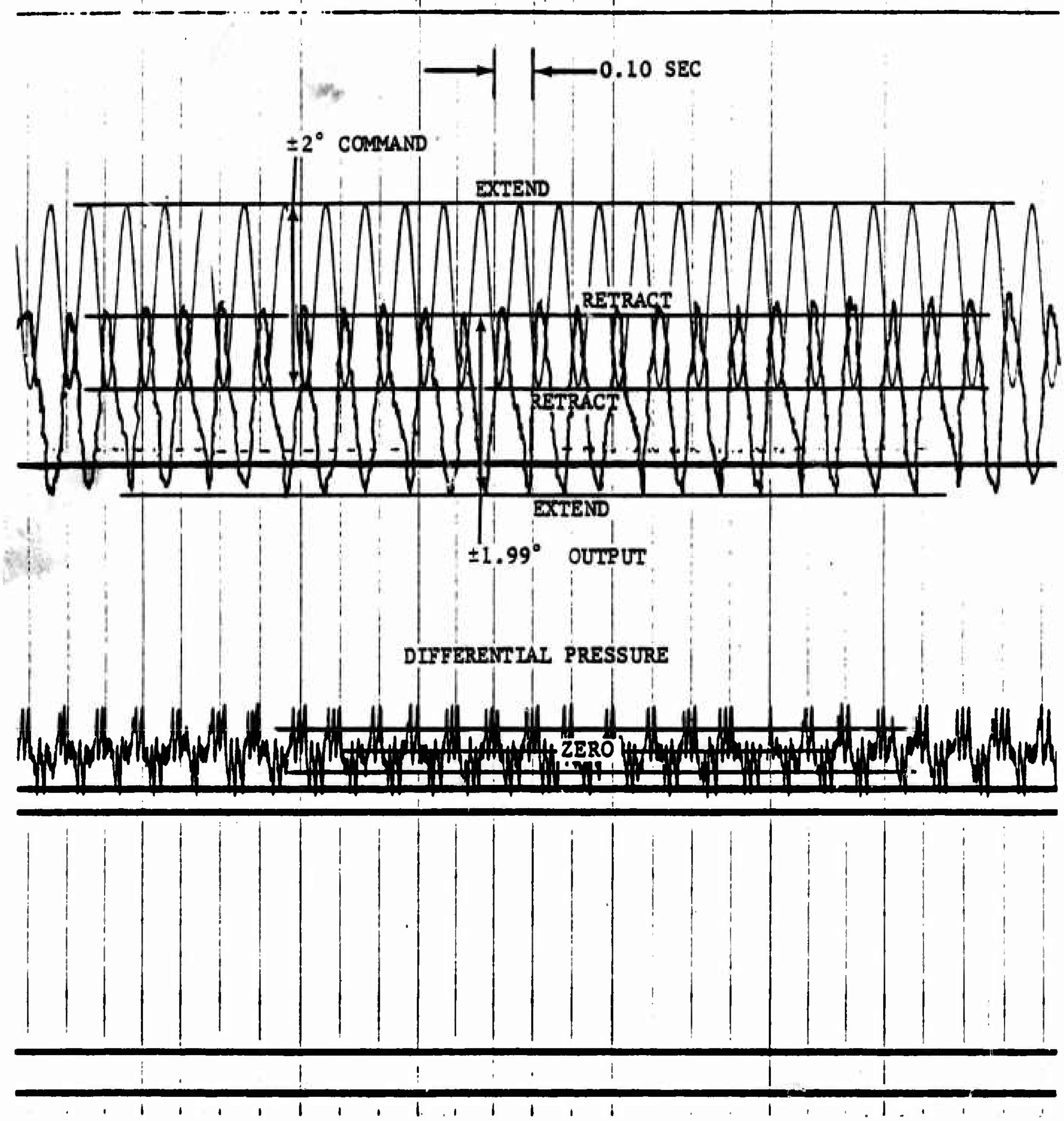


FIGURE 34. Low Load Helium Performance - ±2°, 10 Hz Sine Wave Commands.

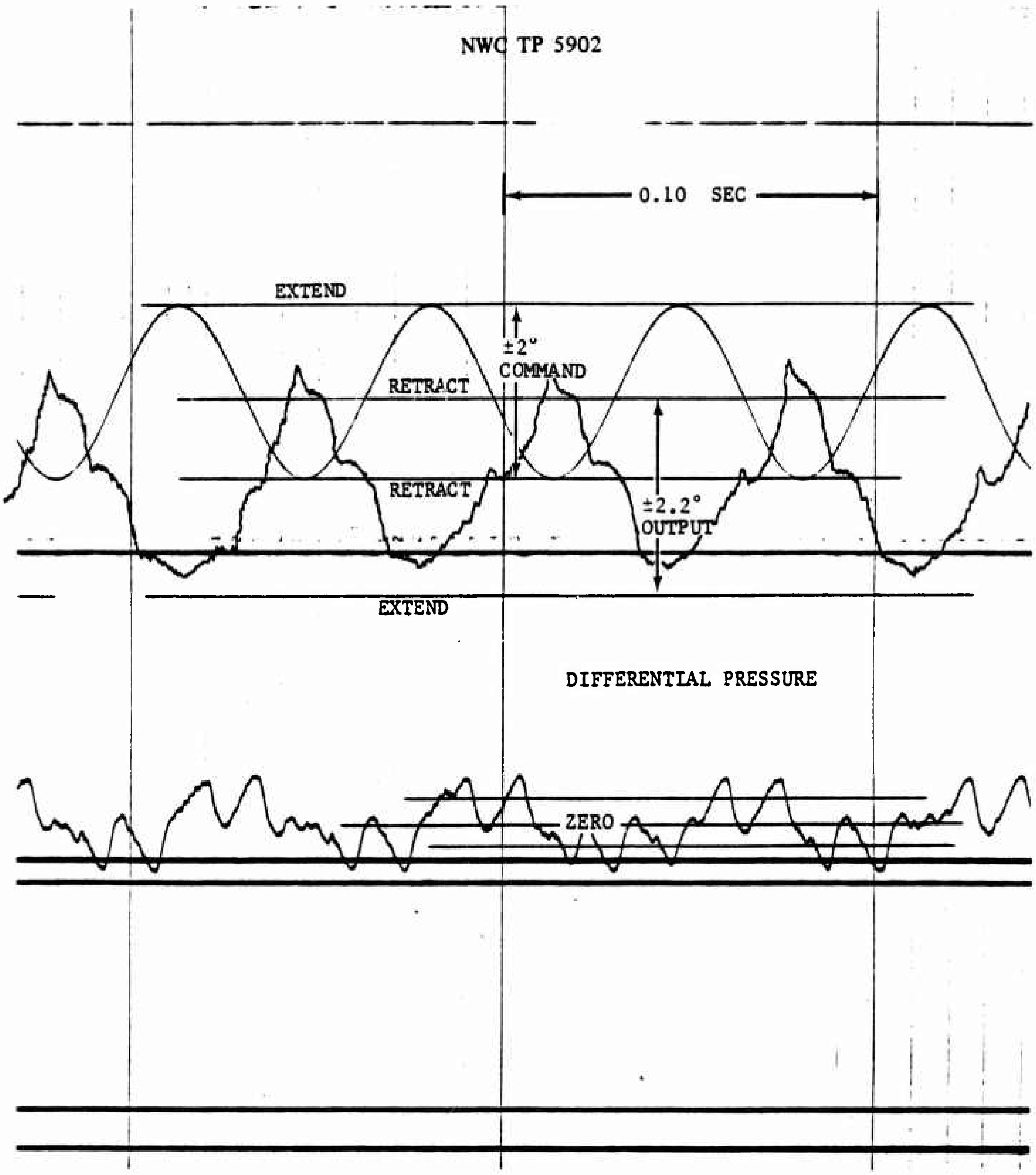


FIGURE 35. Low Load Helium Performance - ±2°, 15 Hz Sine Wave Commands.

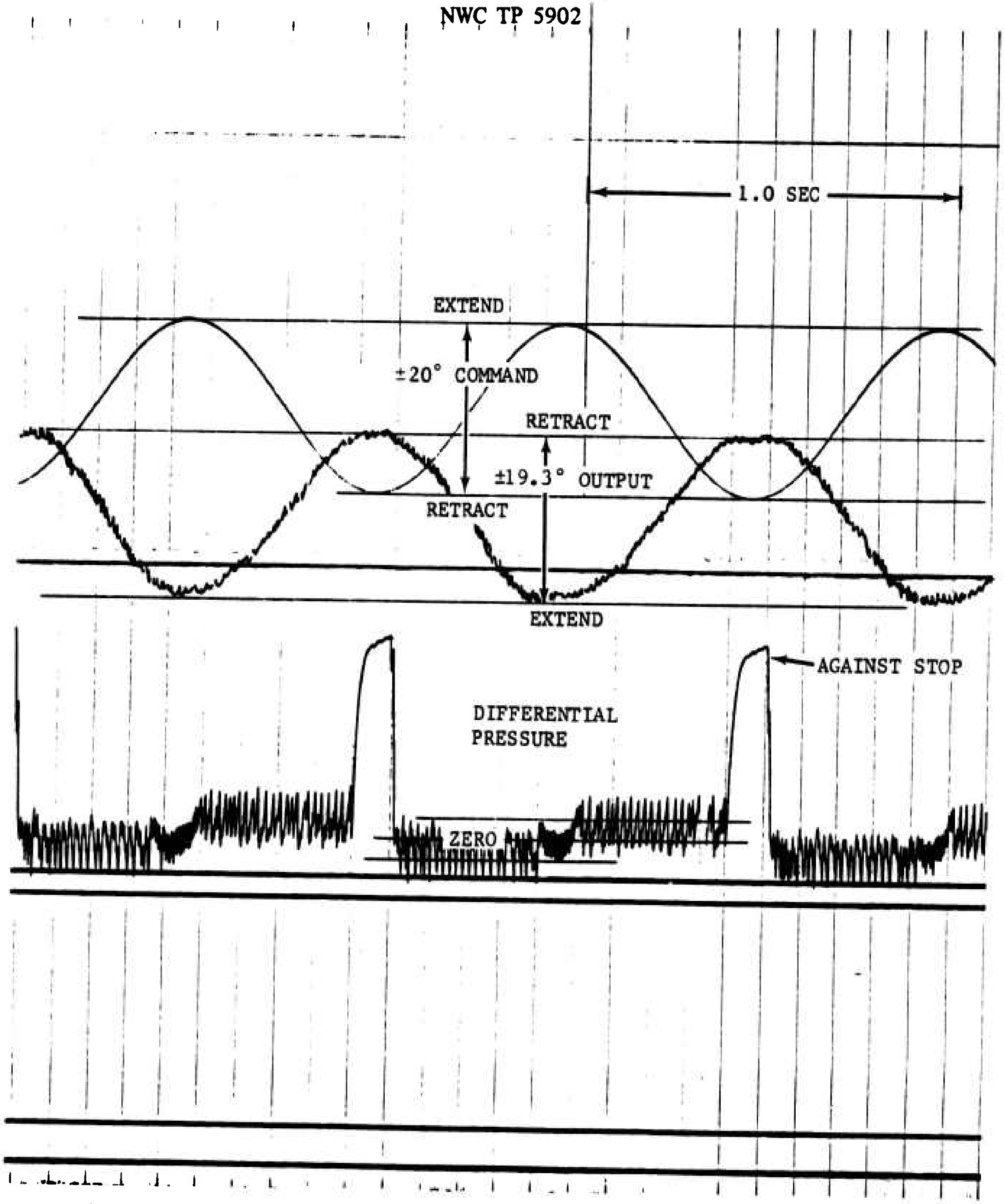


FIGURE 36. Low Load Helium Performance - ±20°, 1 Hz Sine Wave Commands.

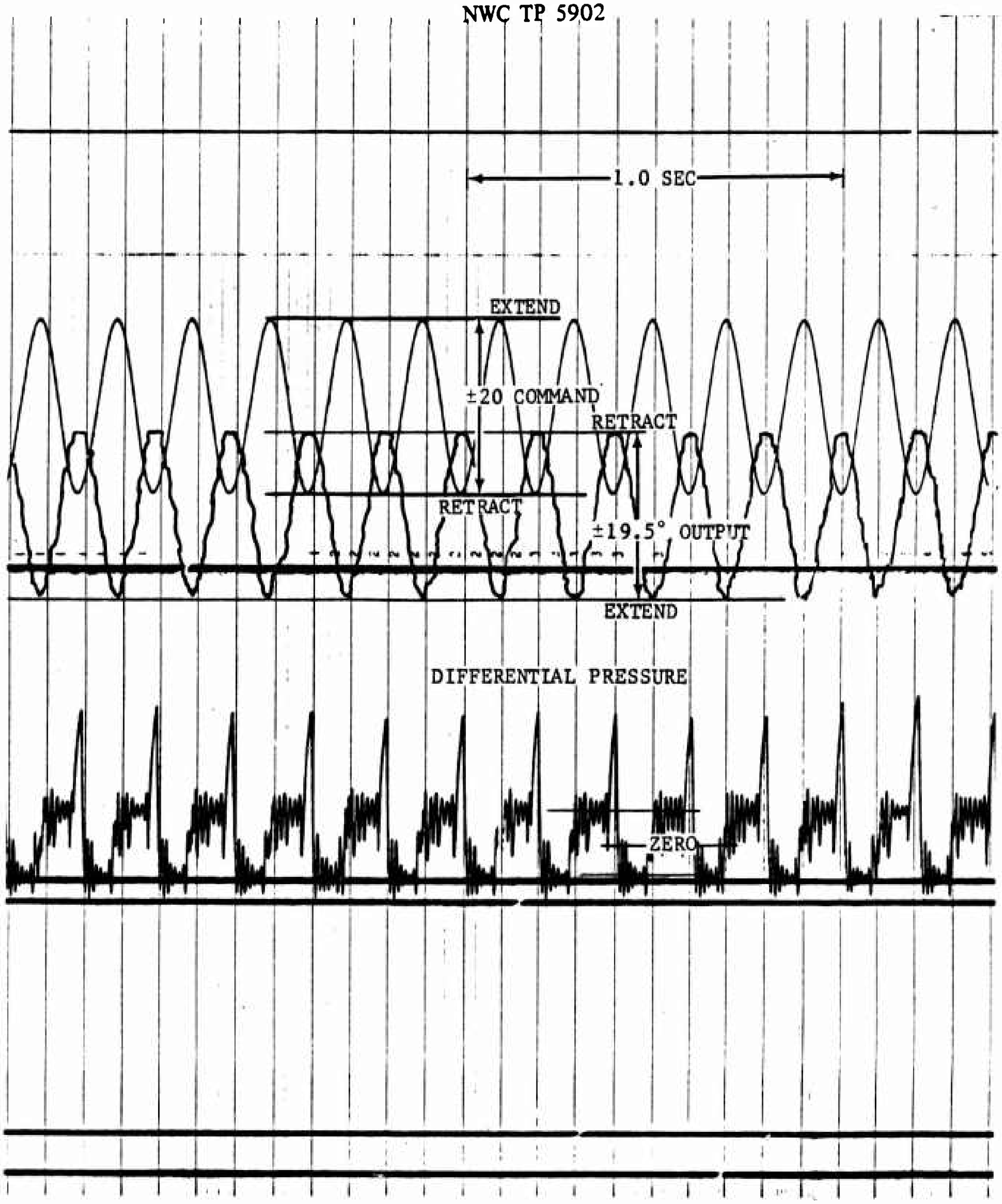


FIGURE 37. Low Load Helium Performance - ±20°, 5 Hz Sine Wave Commands.

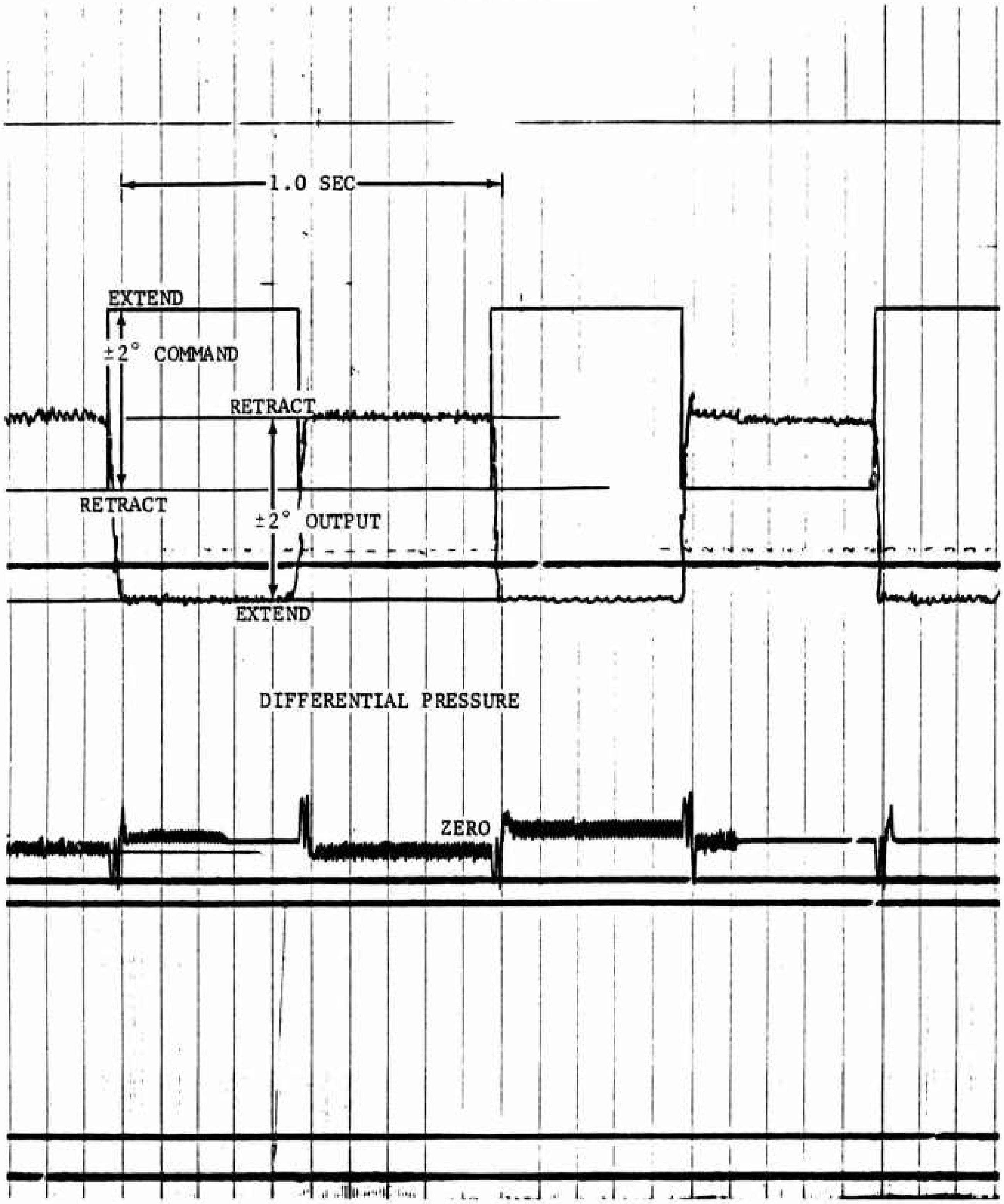


FIGURE 38. Low Load Helium Performance - ±2°, 1 Hz Square Wave Commands.

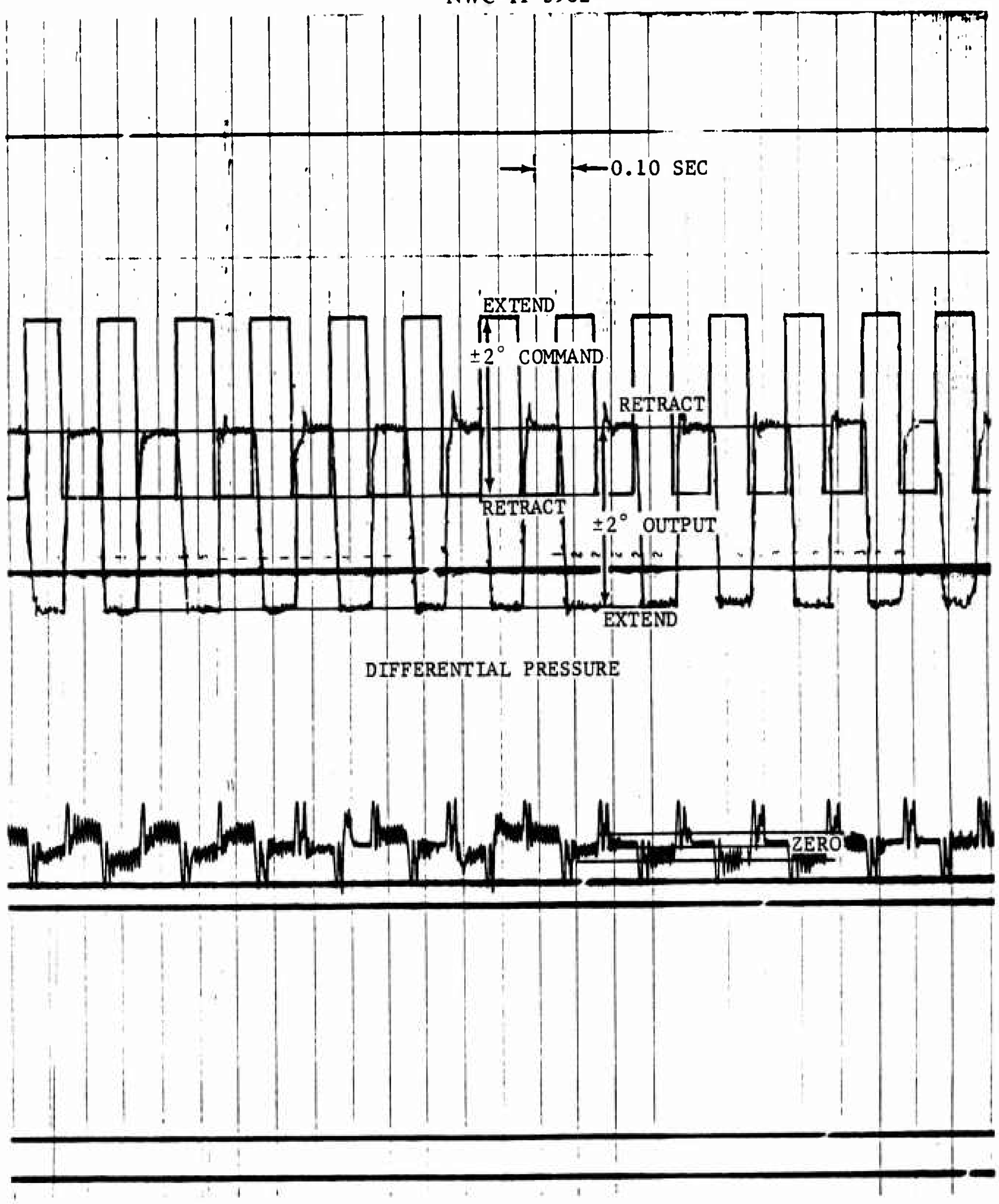


FIGURE 39. Low Load Helium Performance - ±2°, 5 Hz Square Wave Commands.

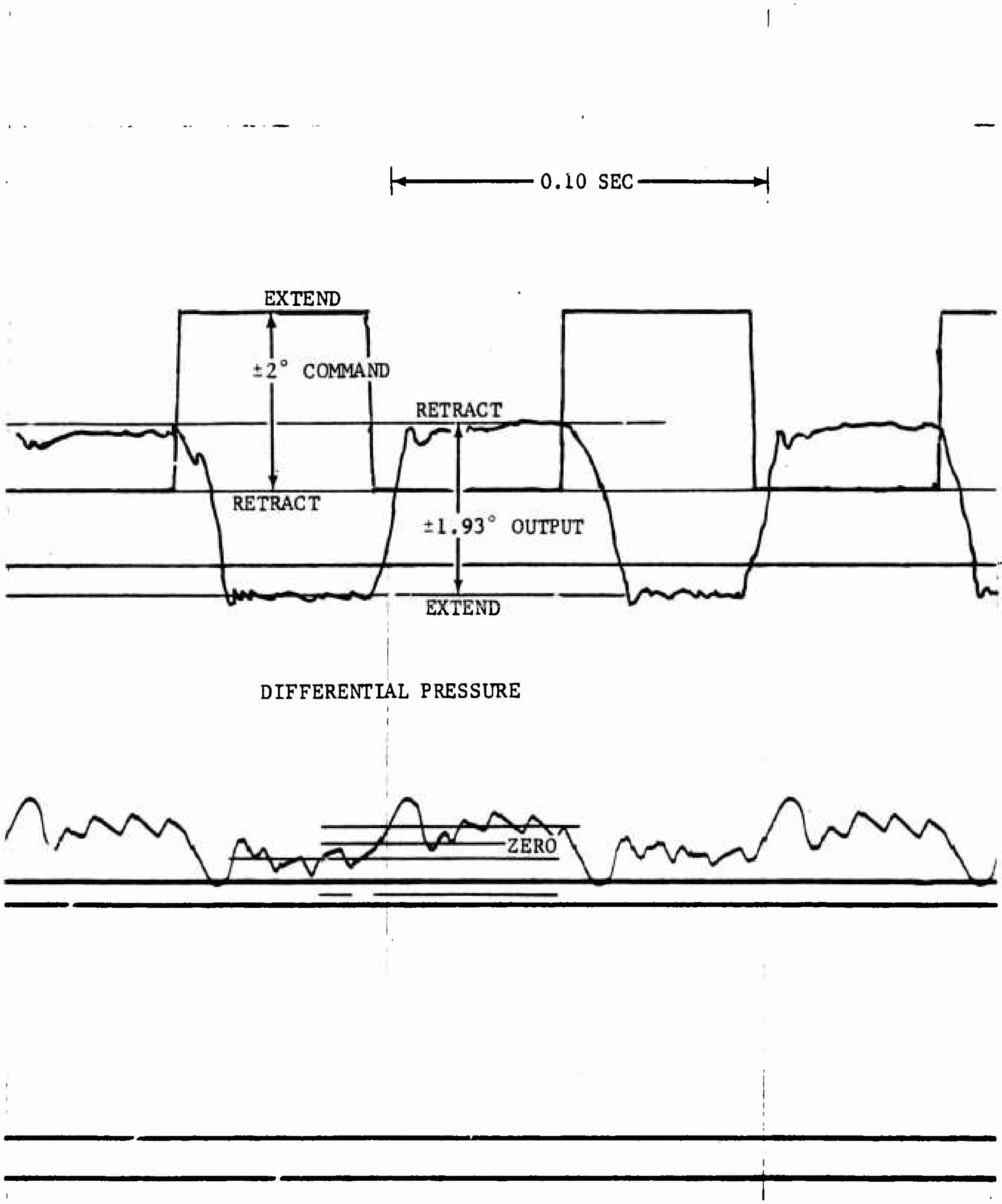


FIGURE 40. Low Load Helium Performance - ±2°, 10 Hz Square Wave Commands.

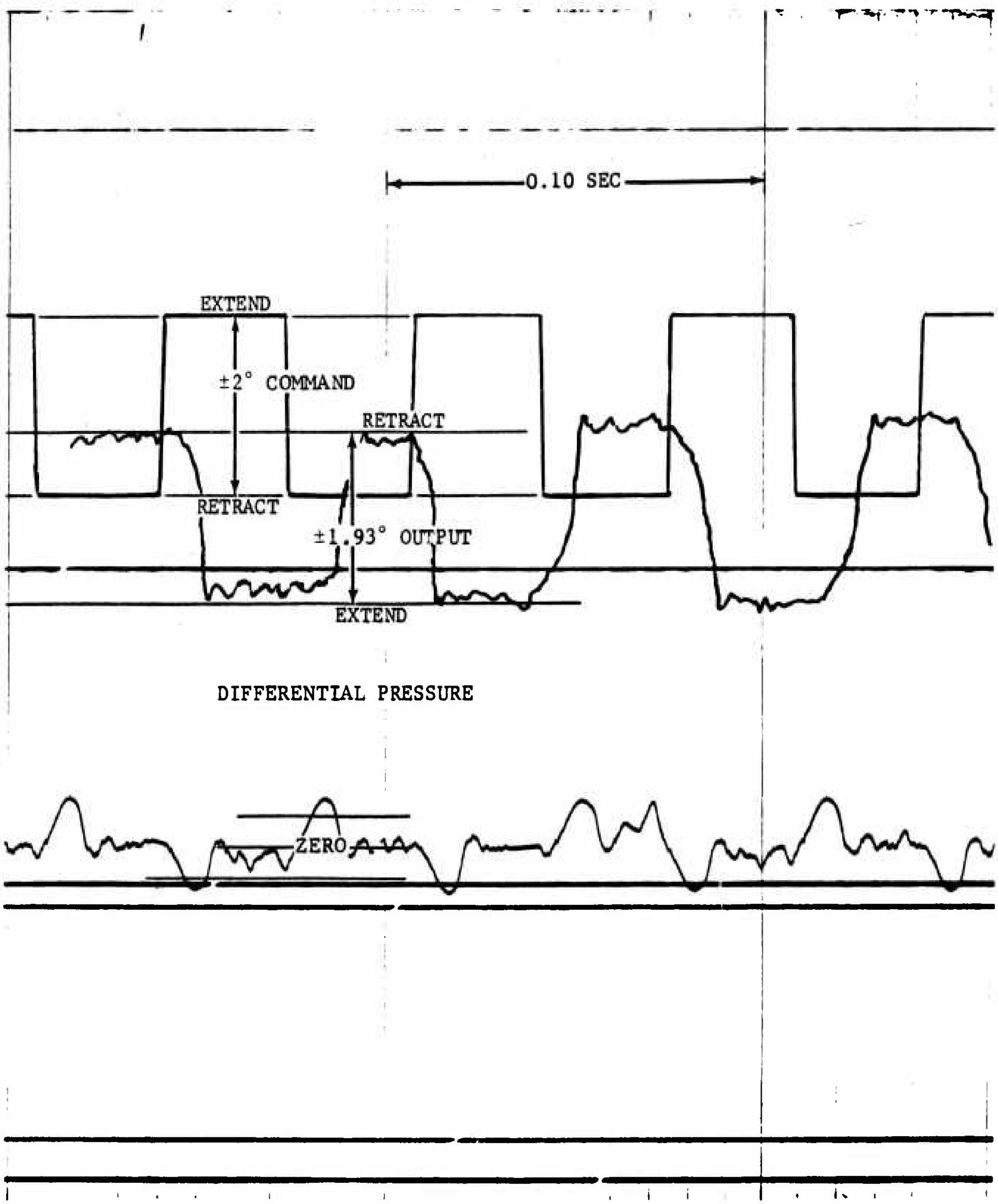


FIGURE 41. Low Load Helium Performance - ±2°, 15 Hz Square Wave Commands.

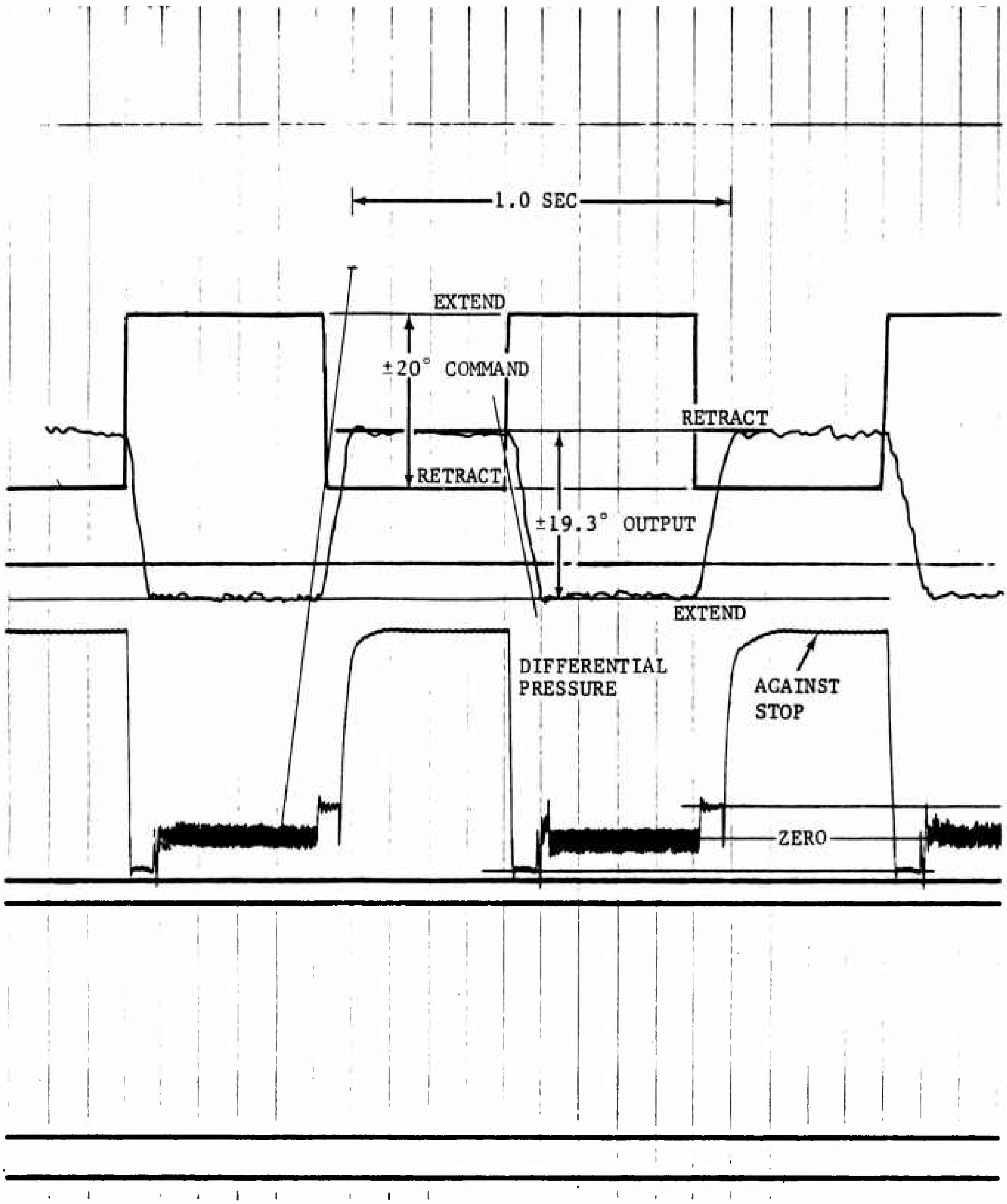


FIGURE 42. Low Load Helium Performance - ±20°, 1 Hz Square Wave Commands.

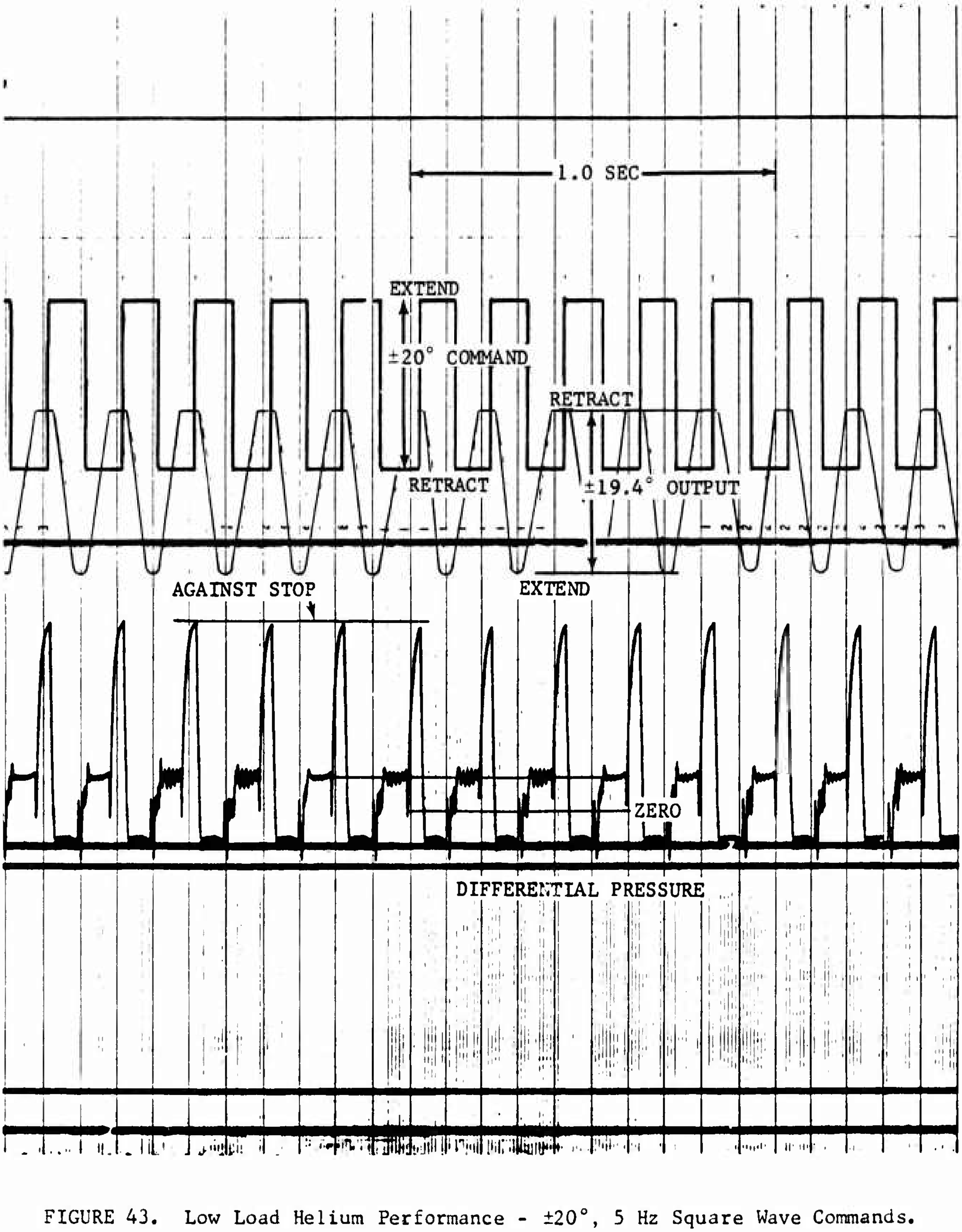


FIGURE 43. Low Load Helium Performance - ±20°, 5 Hz Square Wave Commands.

TABLE 4. Typical Slew Rates for Square Wave Commands, High Load, 2000 psi Helium.

Command	Output (deg)	Slew Rate (deg/sec)
±2°, 1 Hz	±1.83	91.7
±2°, 5 Hz	±1.89	94.4
±2°, 10 Hz	±1.89	94.4
±2°, 15 Hz	±1.46	87.4
±10°, 1 Hz	±9.7	391.0
±10°, 5 Hz	±9.7	391.0
±15°, 1 Hz	±15.0	394.0
±15°, 5 Hz	±12.6	420.0
±20°, 1 Hz	±19.5	432.0
±20°, 5 Hz	±11.3	452.0

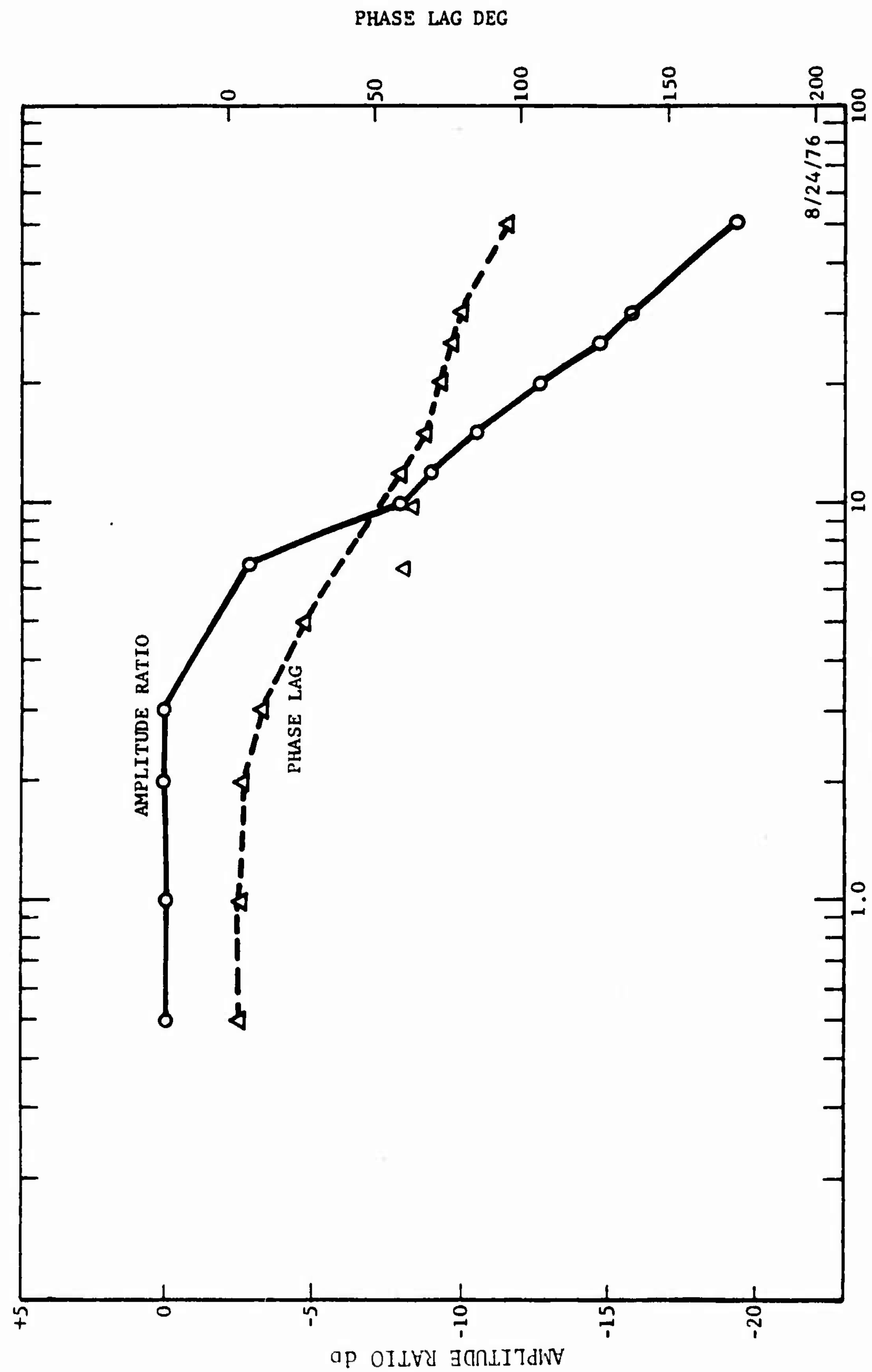


FIGURE 44. NWC Actuator Frequency Response on Nitrogen (with Compensation) - High Load.

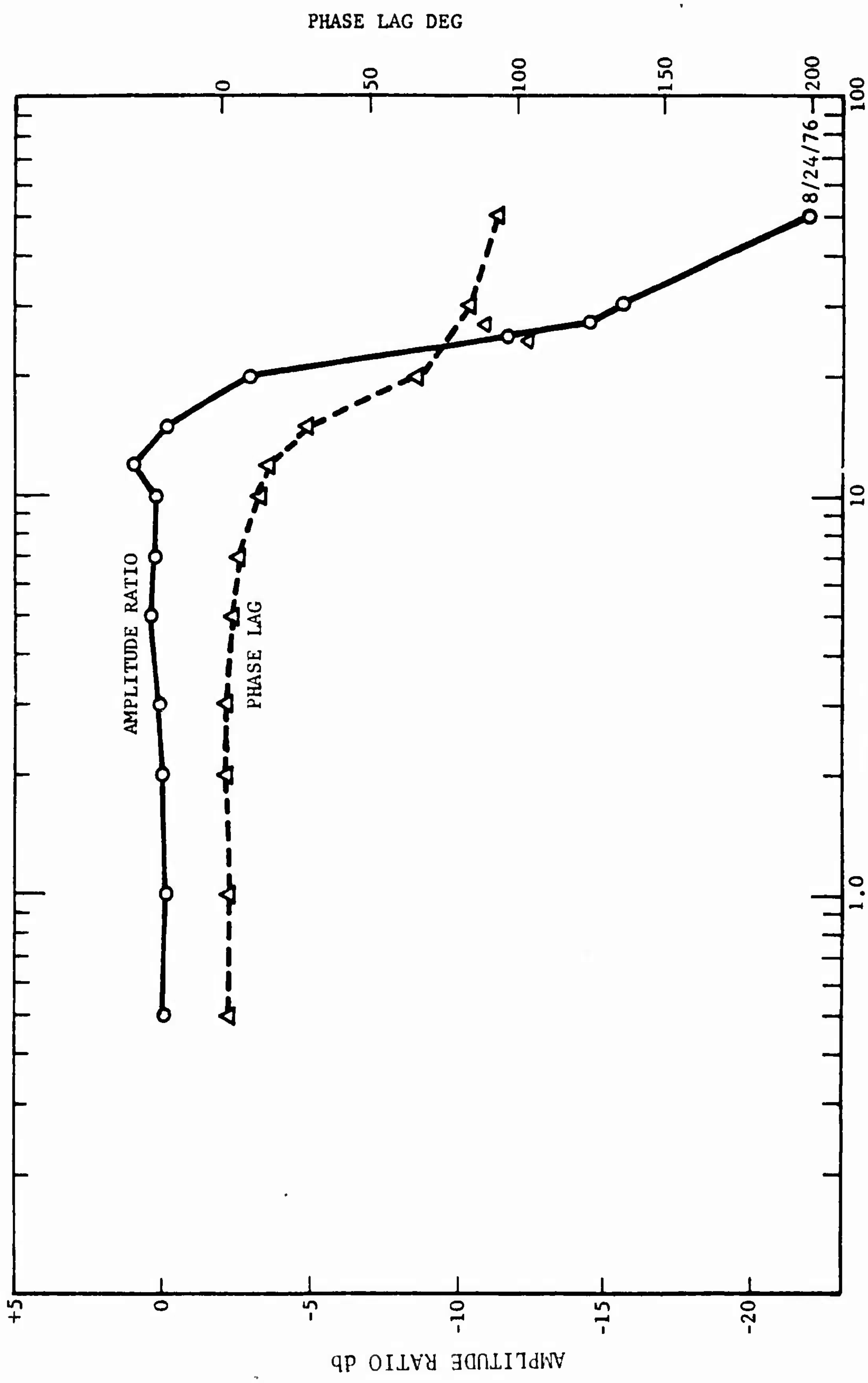
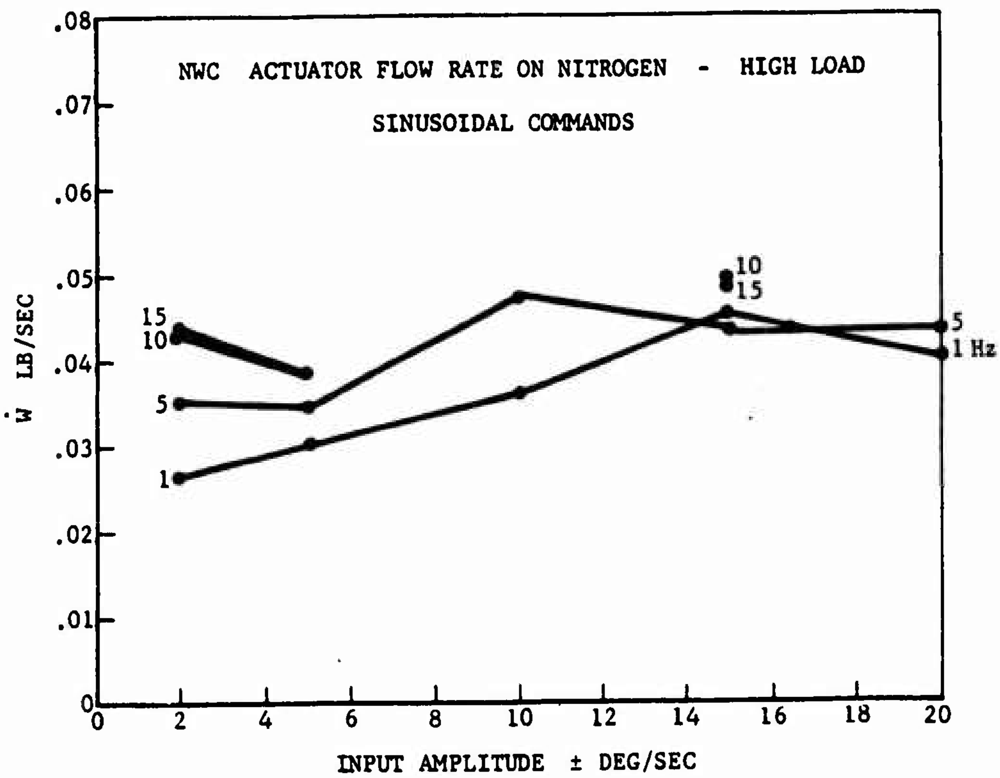


FIGURE 45. NWC Actuator Frequency Response on Nitrogen (with Compensation) - Low Load.



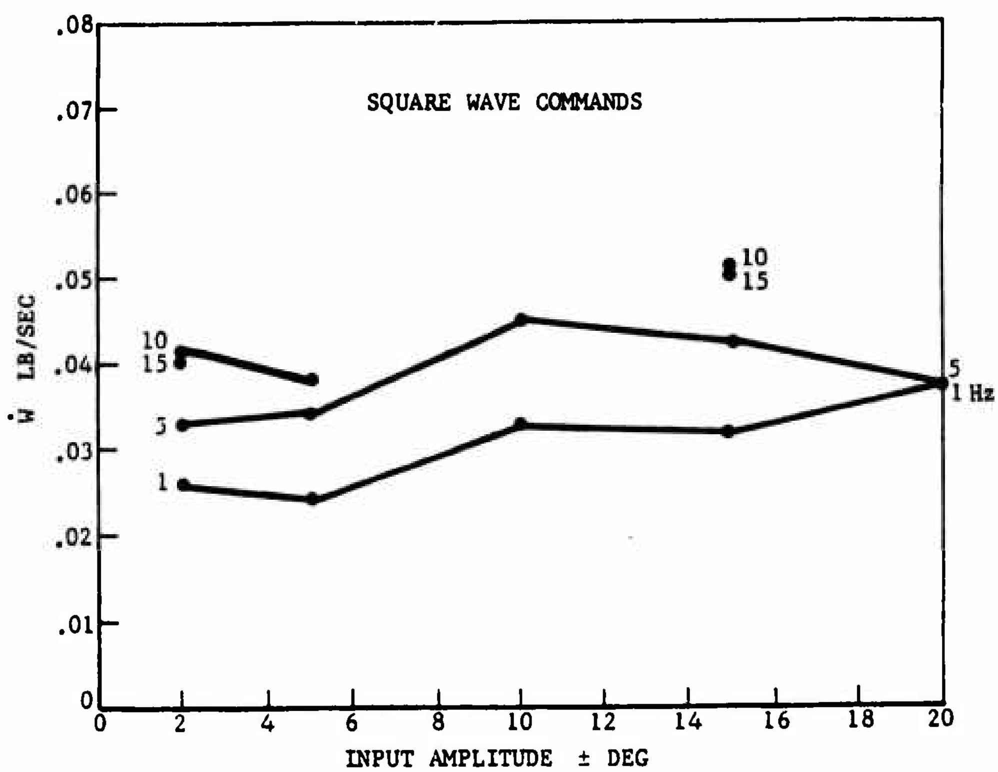
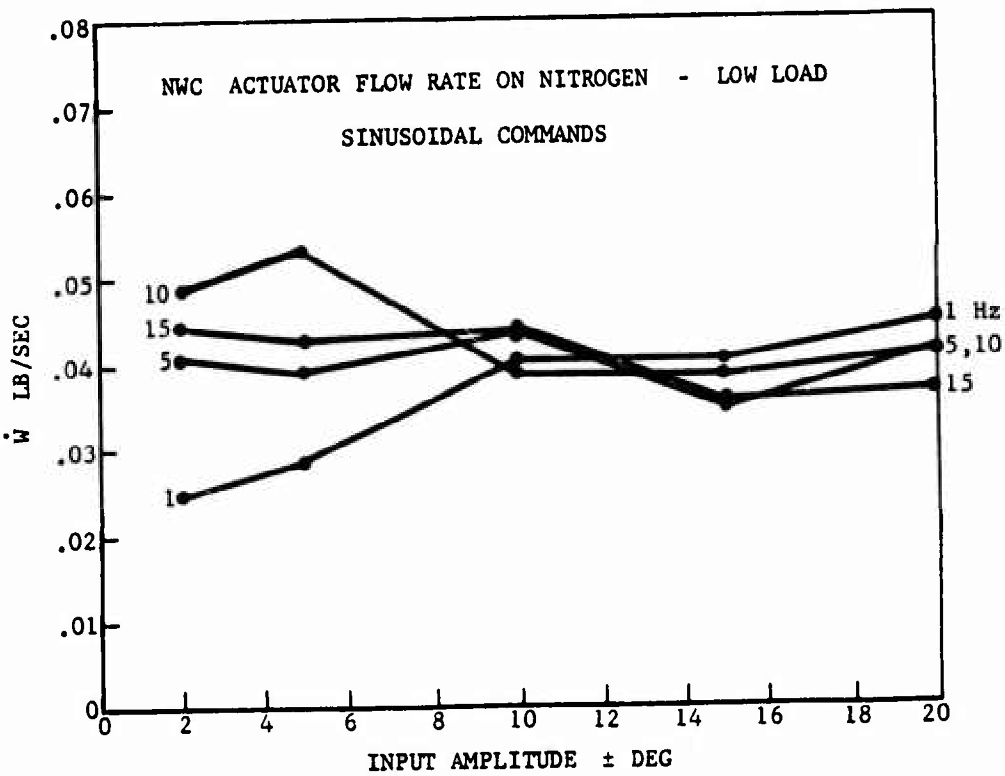


FIGURE 46. NWC Actuator Flow Rate on Nitrogen - High Load.



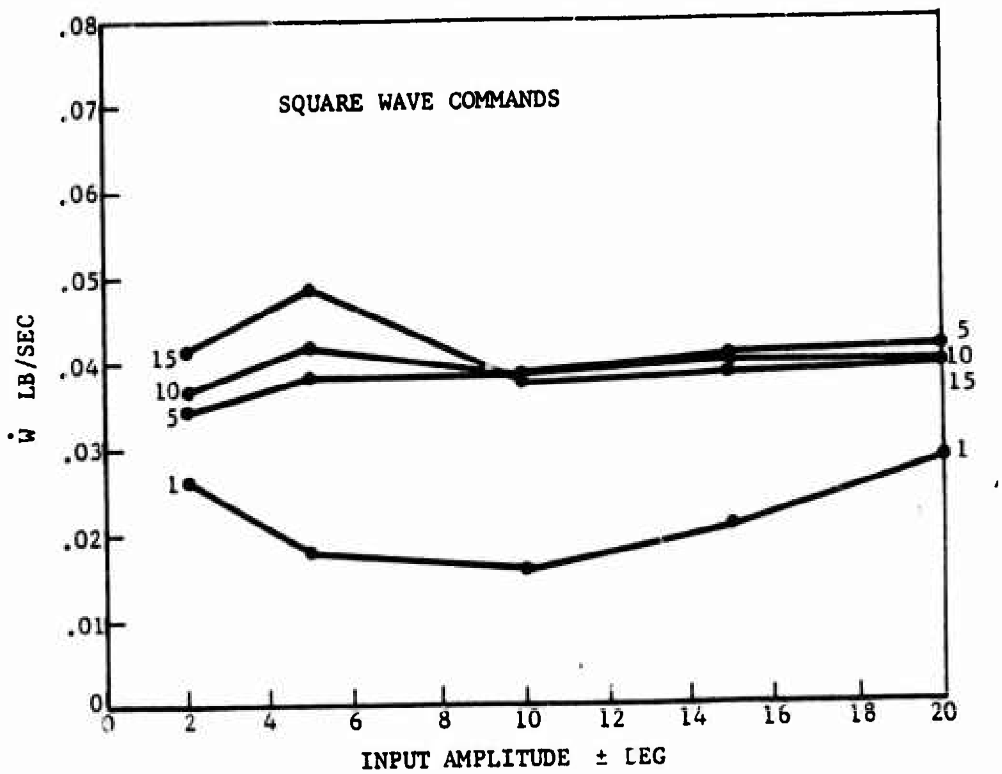


FIGURE 47. NWC Actuator Flow Rate on Nitrogen - Low Load.

TABLE 5. Typical Slew Rates for Square Wave Commands, High Loads, 2000 psi Nitrogen.

Command	Output (deg)	Slew Rate (deg/sec)
±2°, 1 Hz	±1.9	114
±2°, 5 Hz	±1.9	125
±2°, 10 Hz	±0.8	25
±2°, 15 Hz	±0.5	27
±5°, 1 Hz	±4.9	140
±5°, 5 Hz	±5.1	152
±5°, 10 Hz	±0.9	26
±10°, 1 Hz	±10.0	168
±10°, 5 Hz	±6.4	188
±15°, 1 Hz	±15.2	186
±15°, 5 Hz	±7.2	212
±20°, 1 Hz	±19	198
±20°, 5 Hz	±6.9	222

GAS SUPPLY SIZING

Flow measurements in this report were made by monitoring the initial and final pressures in the 145 in^3 gas supply system for 10-second runs at the various operating conditions. To avoid large temperature effect errors, the stable initial and final pressures were used to calculate weight of gas used. For an assumed gas temperature of 80°F, and 10-second runs, the nitrogen flow rate was found as follows:

$$\dot{W}_{GN_2} = \frac{(P_1 - P_2) \text{ psig} \times 145 \text{ in}^3}{55.16 \frac{\text{ft-lb}}{\text{lb°R}} \times 12 \frac{\text{in}}{\text{ft}} \times 540\text{°R} \times 10 \text{ sec}}$$

$$\dot{W}_{GN_2} = \frac{P_1 - P_2}{24651} \text{ lb/sec}$$

For helium the flow rate is:

$$\dot{W}_{HE} = \frac{(P_1 - P_2) \text{ psig} \times 145 \text{ in}^3}{386.30 \frac{\text{ft-lb}}{\text{lb°R}} \times 12 \frac{\text{in}}{\text{ft}} \times 540\text{°R} \times 10 \text{ sec}}$$

$$\dot{W}_{HE} = \frac{P_1 - P_2}{172636} \text{ lb/sec}$$

In conducting the flow rate tests, it became apparent that as the gas supply bottle pressure drops rapidly during periods of high actuator activity, the gas storage temperature drops accordingly. Thus, the actual gas flow rate increases because of the higher gas density flowing into the actuators. For short duration, high activity duty cycles, this situation can have a significant effect on gas bottle sizing because little time is available for the gas supply system components to transfer their heat into the cold helium. Consideration must be given to actual system mass, surface areas, heat capacities, flow rates, and duty cycles to optimize the storage volume requirements. The flow rates for steady ten-second duty cycles, shown in Figures 18 and 19 for helium, and Figures 46

and 47 for nitrogen, were based on initial and final bottle pressure measurements after temperatures had stabilized for 10 to 15 minutes.

In order to provide some preliminary bottle sizing data for typical duty cycles, the actuator was also run at high load on helium following commands which would result in a total activity of 625 degrees in approximately 16 seconds of operation. Typical commands were ±5 deg at 2 Hz, ±10 deg at 1 Hz, and ±20 deg at 0.5 Hz. Both sine and square wave commands were used. Table 6 summarizes the results of these tests utilizing the 145 in^3 test gas supply system. The actual weight of gas used was calculated from the stabilized pressure data and converted to a required bottle volume, based on 10,000 psi initial storage pressure at 140°F. A more conservative bottle volume was also calculated based on typical bottle pressures immediately after shutdown, before the temperatures restabilized. This approach simulates typical missile installations and requirements.

Note that square wave commands require less gas consumption than sinusoidal commands.

TABLE 6. Required Helium Supply for Typical Duty Cycles.

Command	Corrected duration (sec)	Corrected activity (deg)	Stabilized gas used (lb)	Stabilized bottle vol. (in^3)	Indicated gas used (lb)	Required bottle vol. (in^3)
±5° Square Wave, 2 Hz	15.63	625	0.110	30.6	0.143	39.8
±5° Sine Wave, 2 Hz	15.63	625	0.165	45.9	0.191	53.1
±10° Square Wave, 1 Hz	15.63	625	0.120	33.4	0.153	42.6
±10° Sine Wave, 1 Hz	15.63	625	0.169	47.0	0.202	56.2
±20° Square Wave, 0.5 Hz	15.63	625	0.094	26.1	0.122	33.9
±20° Sine Wave, 0.5 Hz	15.63	625	0.171	47.6	0.210	58.4

D120-76-151
Revised 9/30/76

APPENDIX A

ACCEPTANCE TEST PROCEDURE

NWC NOZZLE ACTUATOR

R. Levi

R. Levi HP

CH Lewis

C. H. Lewis, Supervisor
Systems Test Section

NOTE: 1. Tests to be performed using P/N 51040 test stand.

2. Record all data on brown-line copy of this procedure.

Aeronutronic Ford

Aeronutronic Ford Corporation
Aeronutronic Division
Newport Beach, Ca. 92663

NWC NOZZLE ACTUATOR

ACCEPTANCE TEST

P/N 51030 S/N 004

A. Proof Test and Static Leakage

1. Mount assembled actuator on test stand and connect inlet to N_2 source. Apply 3000 psi for 3 minutes. No visible permanent deformation allowed.

C H Lewis — Technician 9/29/76 — Date

2. With 2000 psi N_2 applied attach a flow meter (rotameter) to each exhaust port and record the leakage flow rate.

Valve B (Piston Rod End) 0.180 SCFM S/N 6

Valve A (Clevis End) 0.145 SCFM S/N 15

Leakage for each valve must be less than 0.4 SCFM.

C H Lewis — Technician 9/29/76 — Date

3. Inspect piston rod end seals and flanges for leakage. Also inspect valve mountings including nut and seal screw. All joints to be bubble tight.

C H Lewis — Technician 9/29/76 — Date

P/N 51030

S/N 004

B. Valve Characteristics

Coil Resistance

1. Using a resistance bridge, measure each coil resistance and record.

Valve A 22.82 Ω   Valve B 22.67 Ω

Resistance must be 23 Ω ± 1 Ω.

Cll Lewis   9/29/76

Technician   Date

2. Static Pressure Characteristics

Install pressure transducers. Mount actuator on test fixture and lock in midstroke by use of the centering bar. Apply brake pressure of 500 psi. Apply 2000 psi N_2 to inlet. Record differential cylinder pressure vs. PDM command (± 100%) on the X-Y plotter. Command frequency 0.02 Hz. Controller must be set for 5% to 10% crossover bias. The trace must be similar to that shown in Figure A-1. Attach trace to this data sheet.

Cll Lewis   9/29/76

Technician   Date

C. Performance Characteristics

Mount actuator on test fixture. Connect feedback pot to proper terminals. Set controller gain for 0.2V error = 100% (.6 degrees = 100%). Crossover bias set for 5% to 10% at modulator output. PDM carrier frequency 100 Hz, D.C. power 28V and compensation switch set to "IN". Gas supply to be 2000 psi helium.

Frequency Response

1. Set brake pressure to 275 psi. Connect Weston frequency response analyzer to controller. Adjust analyzer output command for ± 0.7V (± 2°). Apply pressure to servo and record amplitude and phase lag at 15 Hz.

P/N 51030
S/N 004

Amplitude 0.843 V. Must be less than .98V and greater than .49V.

Phase -29.2 deg. Must be less than -90°.

Clf Lewis
Technician

9/29/76
Date

2. Set brake pressure to 60 psi and repeat (1).

Amplitude 0.806 V. Must be less than .98V and greater than .49V.

Phase +1.7 deg. Must be less than -90°.

Clf Lewis
Technician

9/29/76
Date

Slew Rate

3. Set controller to 1 Hz square wave. Adjust analyzer command to maximum voltage. Set brake pressure to 275 psi. Record on Sanborn recorder position and command for hardover inputs to controller. Determine average slew rate by slope of position trace. Attach recorder trace to original data sheet.

Average slew rate 513 °/sec, extend.

Average slew rate 513 °/sec, retract.

Must be 400°/sec, minimum.

Clf Lewis
Technician

9/29/76
Date

P/N 51030
S/N 004

Hysteresis-Resolution

4. Using a Wavetek or HP low frequency command generator run the following plots on the X-Y plotter recording position and command. Brake pressure 275 psi, command 0.05 Hz. Attach plotter charts to this data sheet.

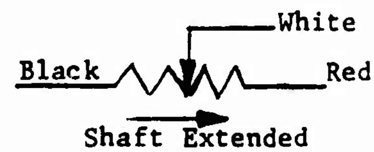
   a) Command amplitude ± 7.5V. Trace should be similar to that shown in Figure A-2.

   b) Command amplitude ± .7V. Trace must be similar to that shown in Figure A-3 (1° maximum deviation from command).

Technician: __________ Date: 9/29/76

D. Potentiometer Characteristics

Serial Number 3276-236 Orientation



Measure resistance between black and red leads and record value.

3.179 KΩ (nom. 3KΩ)

Position actuator at mid-stroke and apply excitation voltage. Read excitation voltage and wiper voltage.

Excitation: Positive 11.22 VDC
Negative 11.38 VDC

Wiper: -195 mVDC (Voltage should be within ± 1000 mVDC)

Technician: __________ Date: 9/29/76

Actuator Performance Acceptable

Engineer: __________ Date: 10/1/76

NOTE: All data must contain scale factors and identification of all conditions including actuator serial num'er.

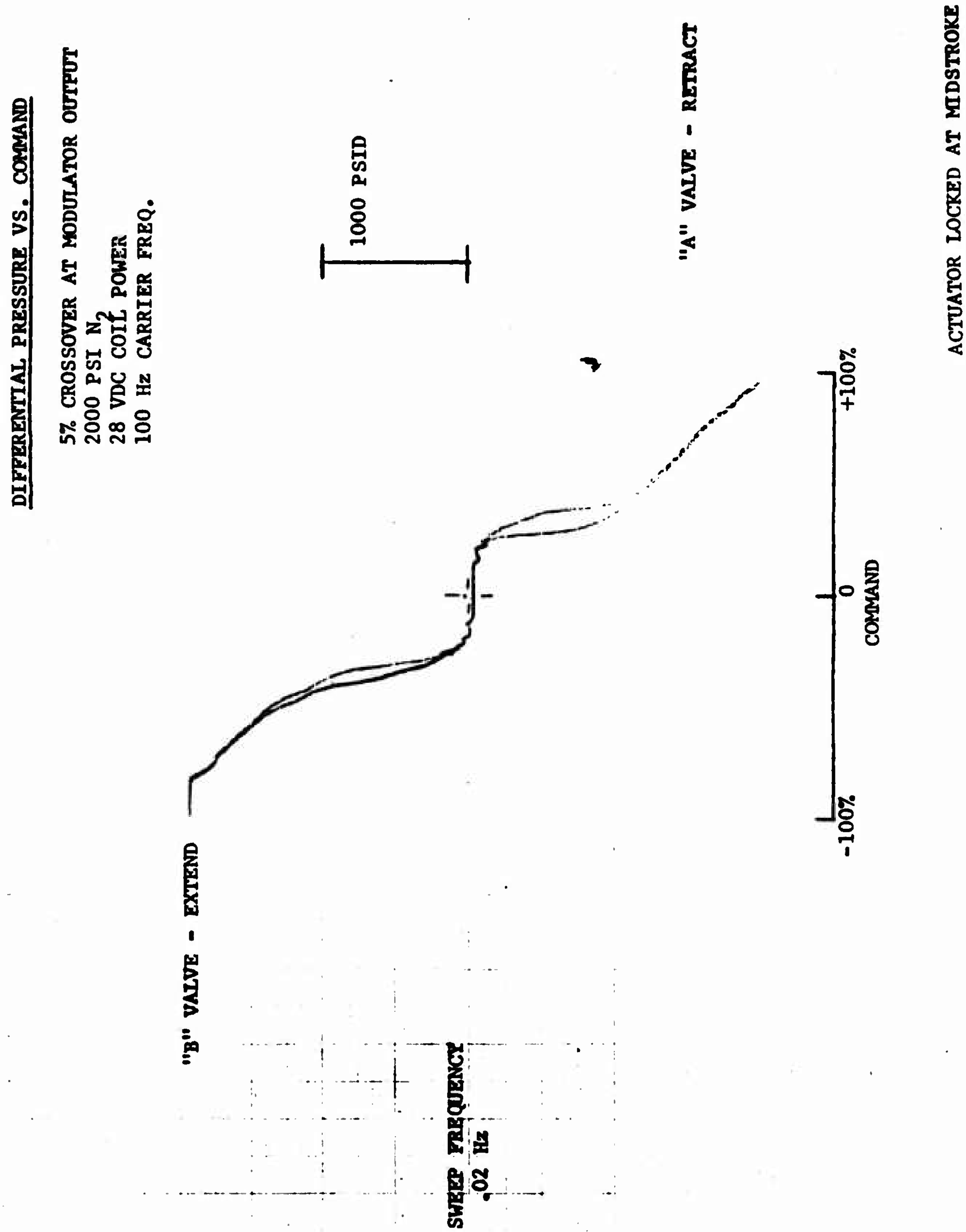

DIFFERENTIAL PRESSURE VS. COMMAND
5% CROSSOVER AT MODULATOR OUTPUT
2000 PSI N_2
28 VDC COIL POWER
100 Hz CARRIER FREQ.
1000 PSID
"A" VALVE - RETRACT
"B" VALVE - EXTEND
-100%
0
+100%
COMMAND
ACTUATOR LOCKED AT MIDSTROKE
SWEEP FREQUENCY
.02 Hz

FIGURE A-1.

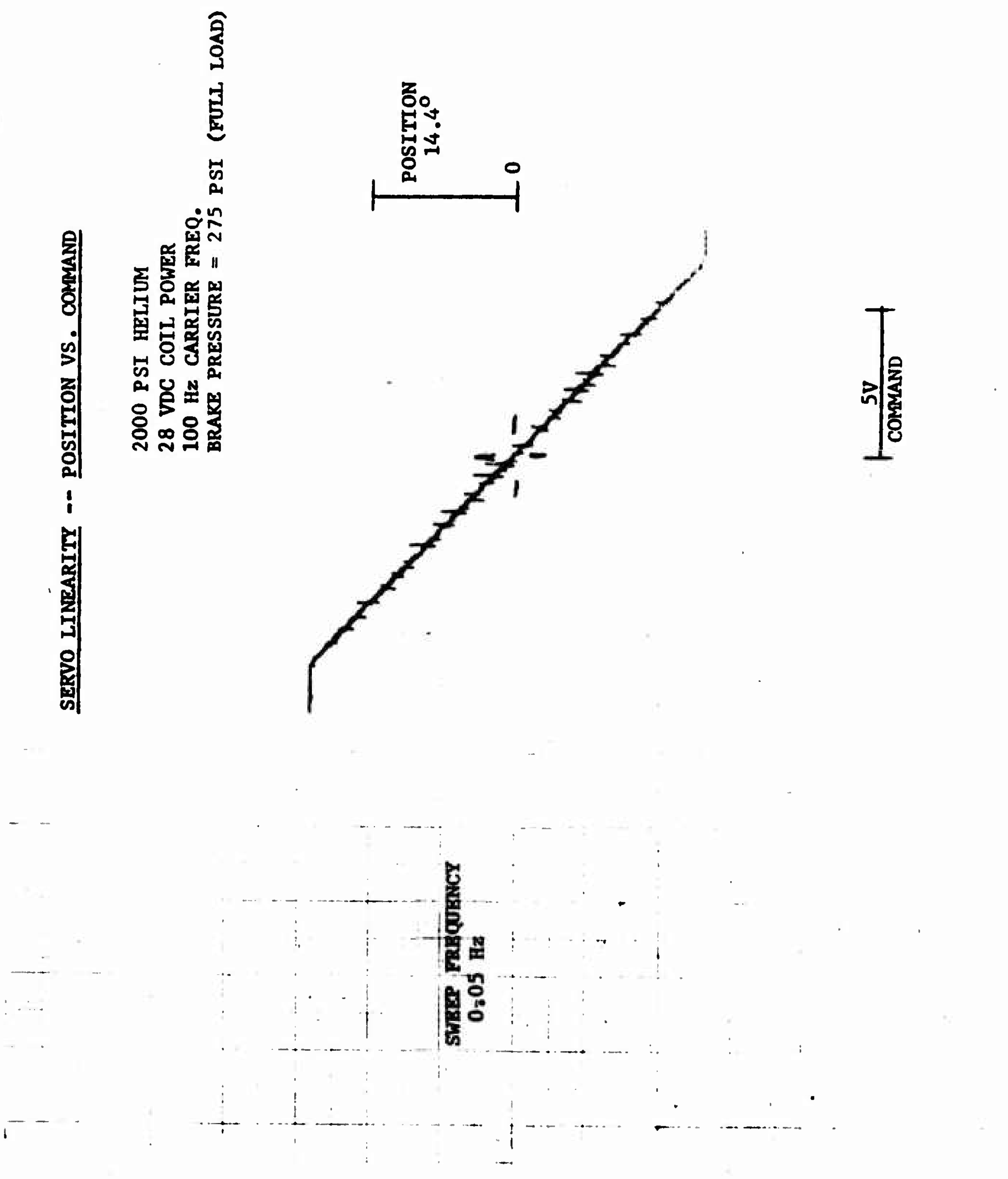

SERVO LINEARITY -- POSITION VS. COMMAND
2000 PSI HELIUM
28 VDC COIL POWER
100 Hz CARRIER FREQ.
BRAKE PRESSURE = 275 PSI (FULL LOAD)
POSITION
14.4°
0
5V
COMMAND
SWEEP FREQUENCY
0.05 Hz

FIGURE A-2.

HYSTERESIS & RESOLUTION - POSITION VS. COMMAND

2000 PSI HELIUM
28 VDC COIL POWER
100 Hz CARRIER FREQ.
BRAKE PRESSURE = 275 PSI (FULL LOAD)

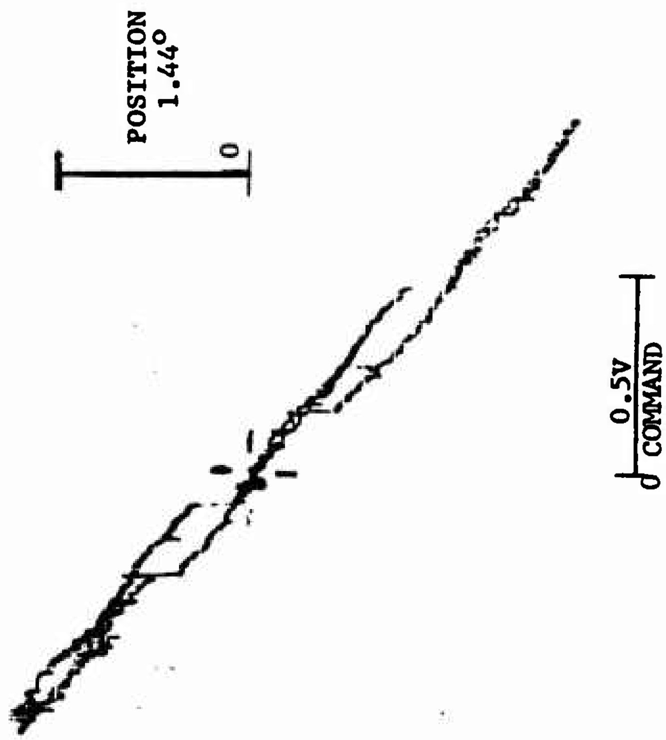


FIGURE A-3.

APPENDIX B

COST STUDY TECHNICAL REPORT

INTRODUCTION

Aeronutronic Division of Aeronutronic Ford Corporation is currently working under contract N123-76-C-0286 from the Naval Weapons Center to complete the design and development of a Servo Actuator initiated under prior contracts, and to fabricate, assemble, check-out and deliver six flight items in addition to one development model. Prior design and development work was performed for the Naval Weapons Center under contracts N60530-75-M-829C and N60530-76-M-525V.

The Servo Actuator is a cold gas pneumatic actuator which provides thrust vector control of a tactical missile by positioning the rocket motor nozzle. A Servo Actuator missile system consists of a cold gas reservoir, squib valve and pressure regulator (these items comprise the helium power supply) and four solenoid valves, two piston cylinder assemblies, and two potentiometers (the actuator) with appropriate plumbing and wiring.

There are two configurations - a rear-mounted helium power supply and a forward-mounted helium power supply - as illustrated in Figure 1 of the main text and Figure B-1. Figure B-2 shows the Servo Actuator, and Figure B-3 shows one actuator mounted on an NWC-furnished trapped ball nozzle. Figure B-4 shows a cross-section view of the Servo Actuator.

The forward-mounted helium power supply requires one large, spherical reservoir, and the rear-mounted helium power supply requires three smaller, cylindrical, manifolded reservoirs, as constrained by the allowable envelope space.

This cost study presents cost estimates for production of Servo Actuator systems at the rate of 2,000 systems per year. This report is a study only and shall not be construed as a proposal on the part of Aeronutronic. Costs are presented in 1976 dollars for recurring effort only and do not include fee.

Costs are summarized as follows:

	2,000 missile systems/year	
	Rear-mounted	Forward-mounted
Total cost	$1,882,602	$1,755,436
Missile-system cost	$941	$878

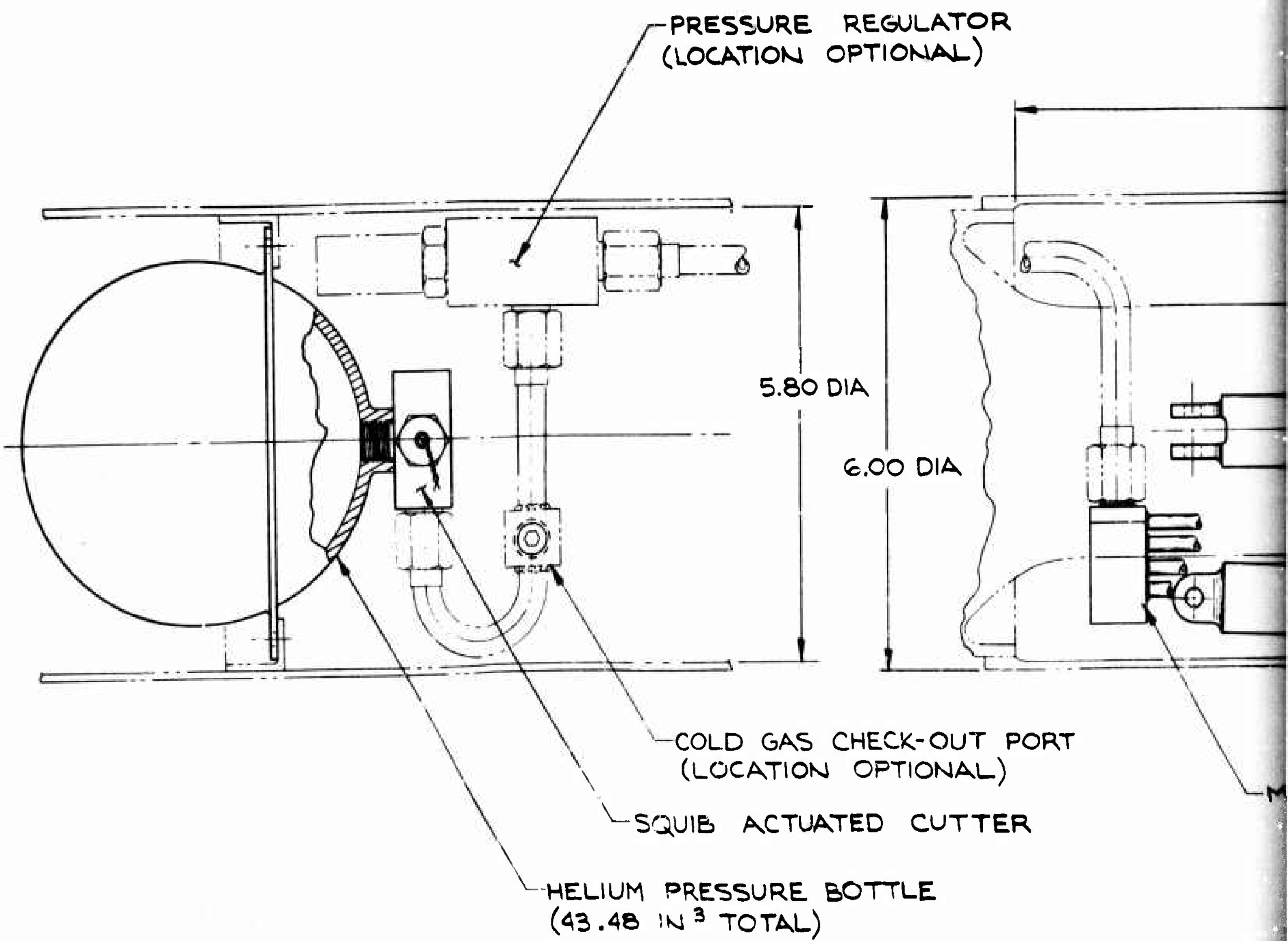
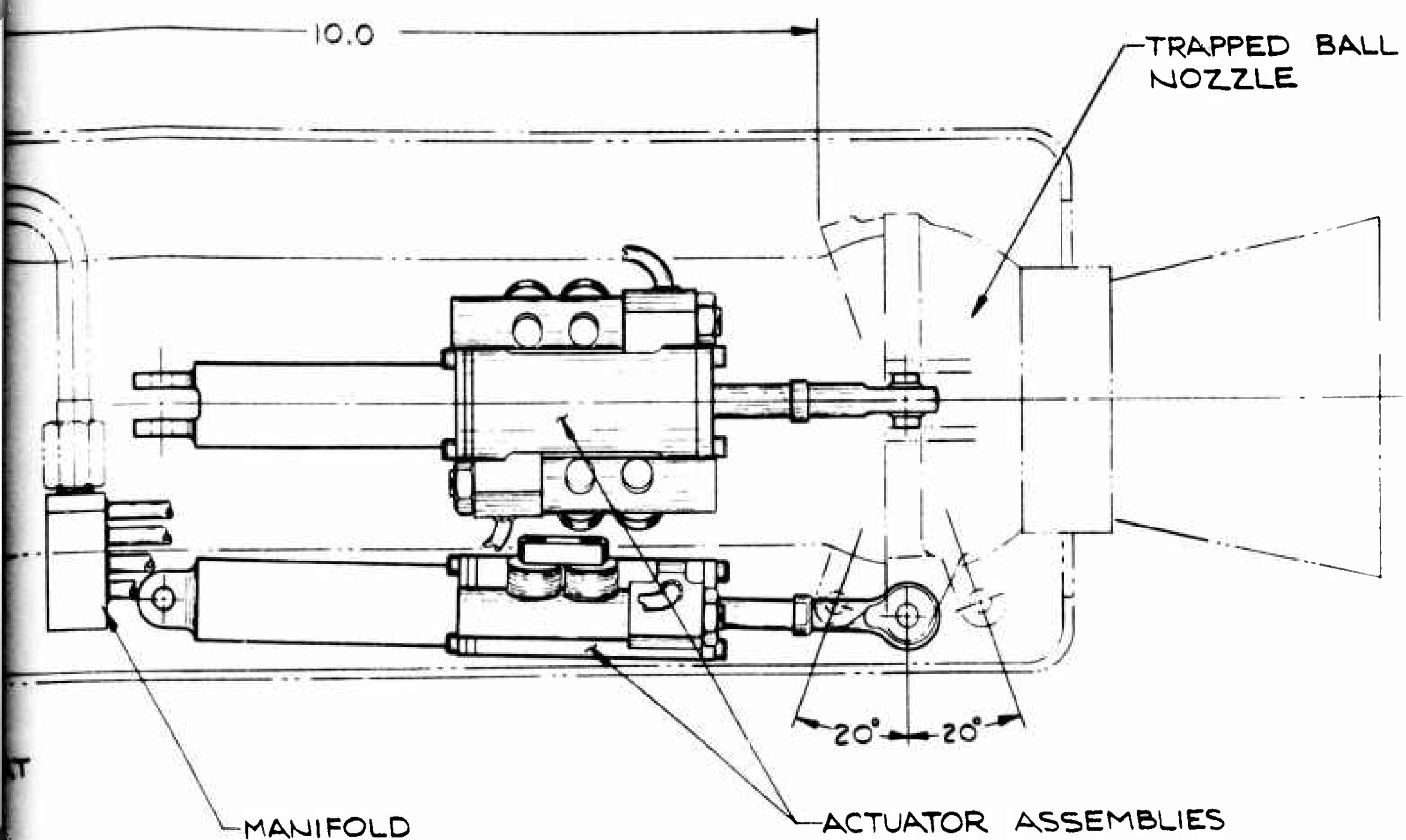


FIGURE B-1. Servo-Actuator, Forwa
Helium Power Supply.



vo-Actuator, Forward-Mounted
ply.

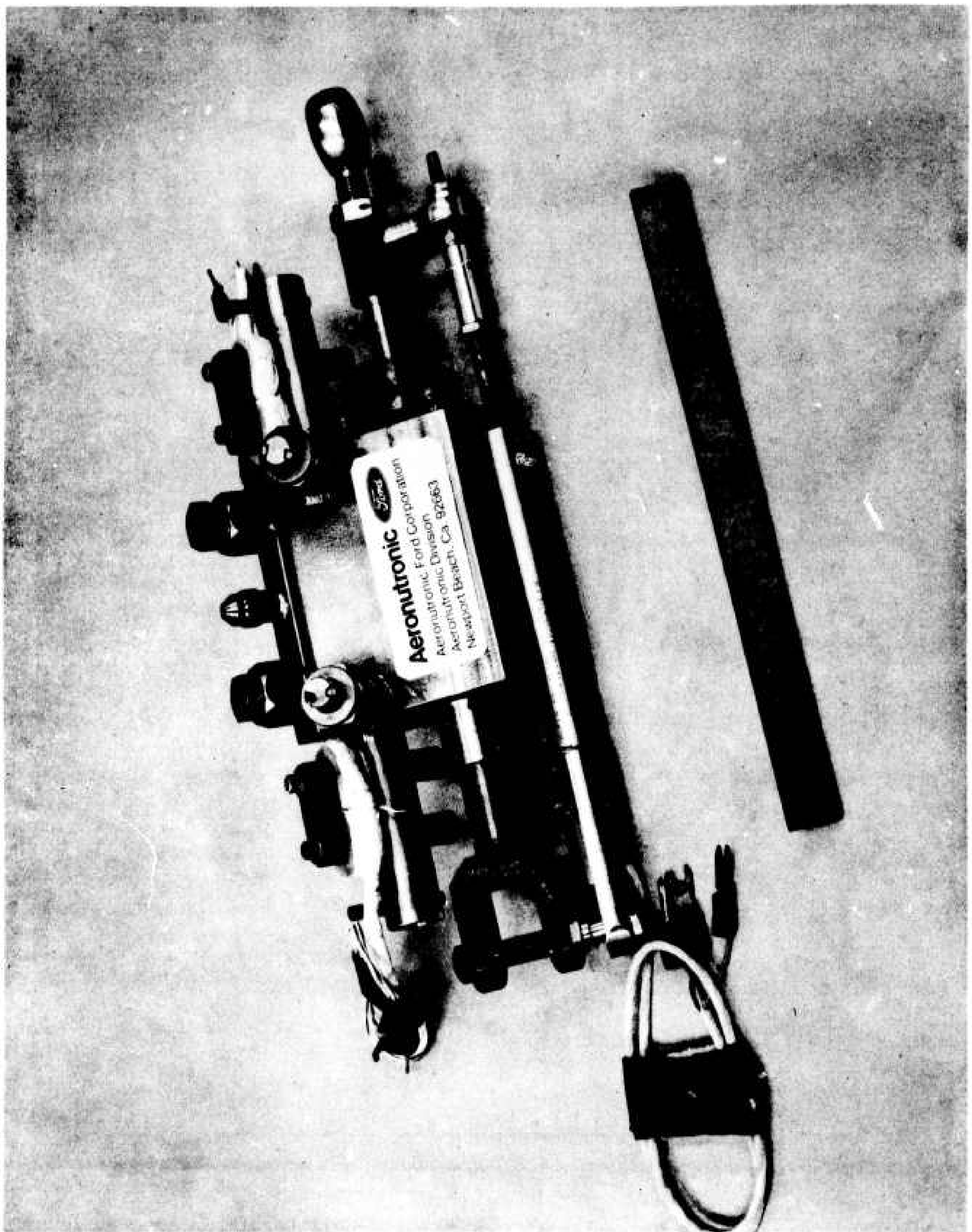


FIGURE B-2. NWC Actuator.

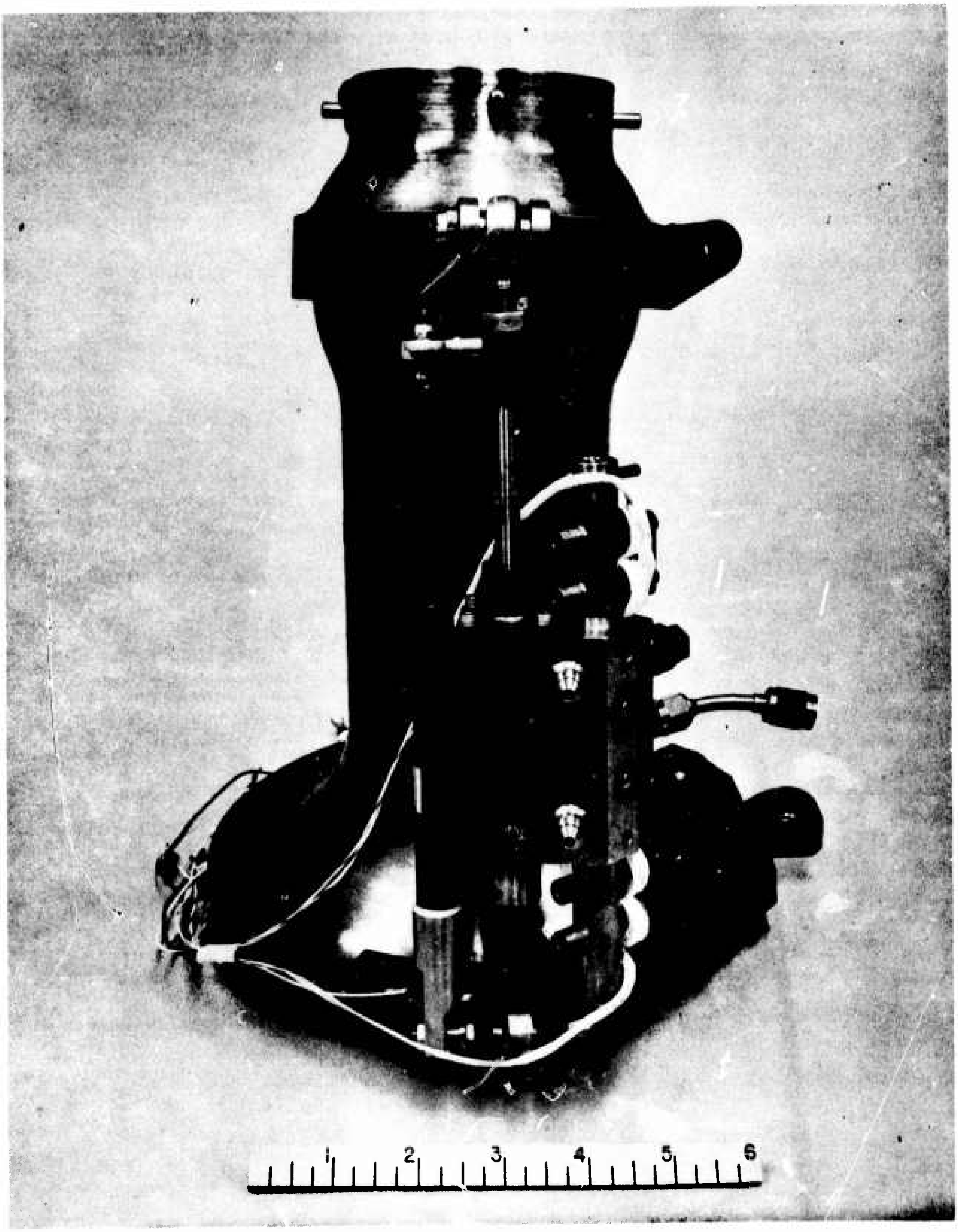


FIGURE B-3. Actuator on Trapped-Ball Nozzle.

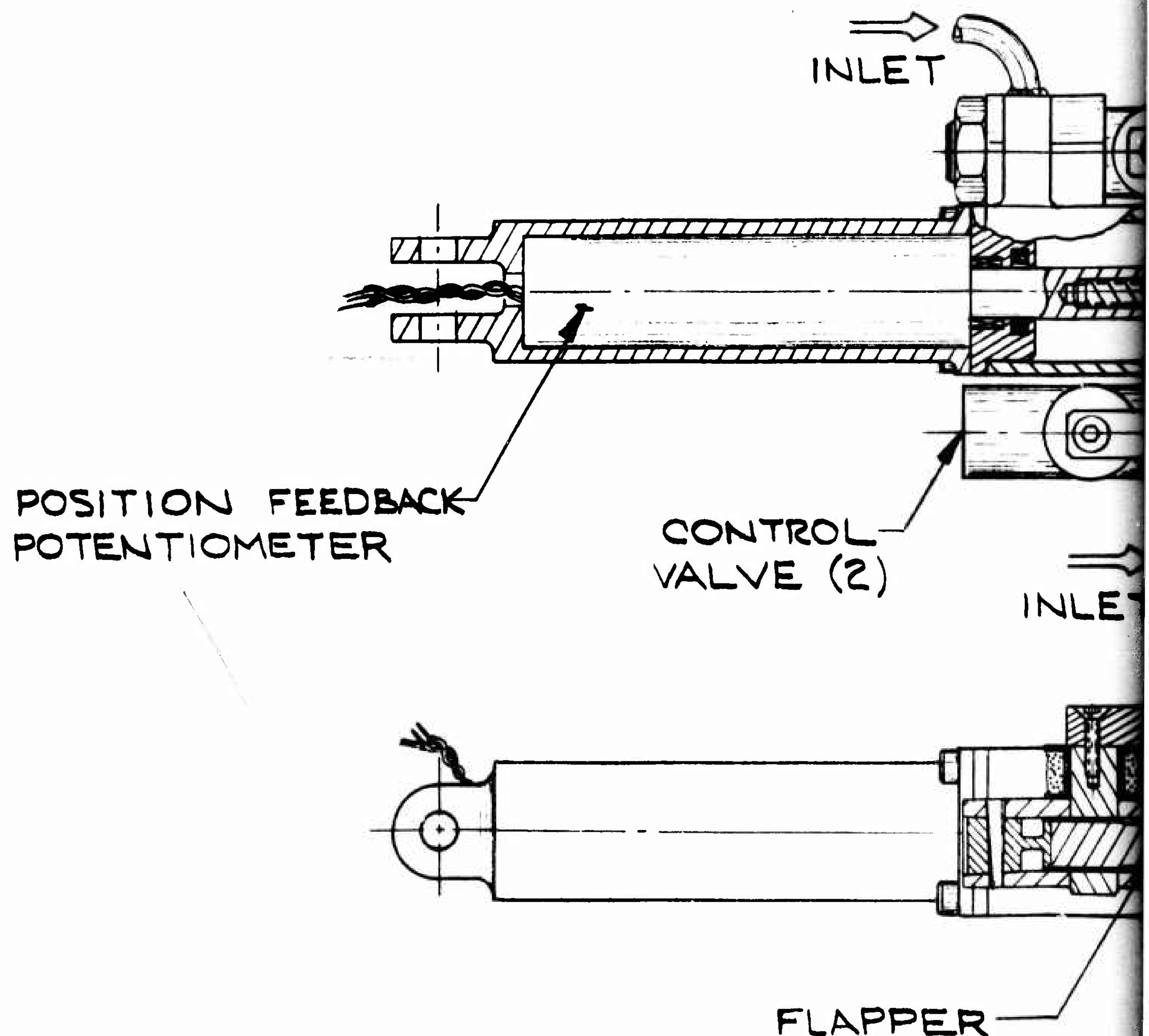
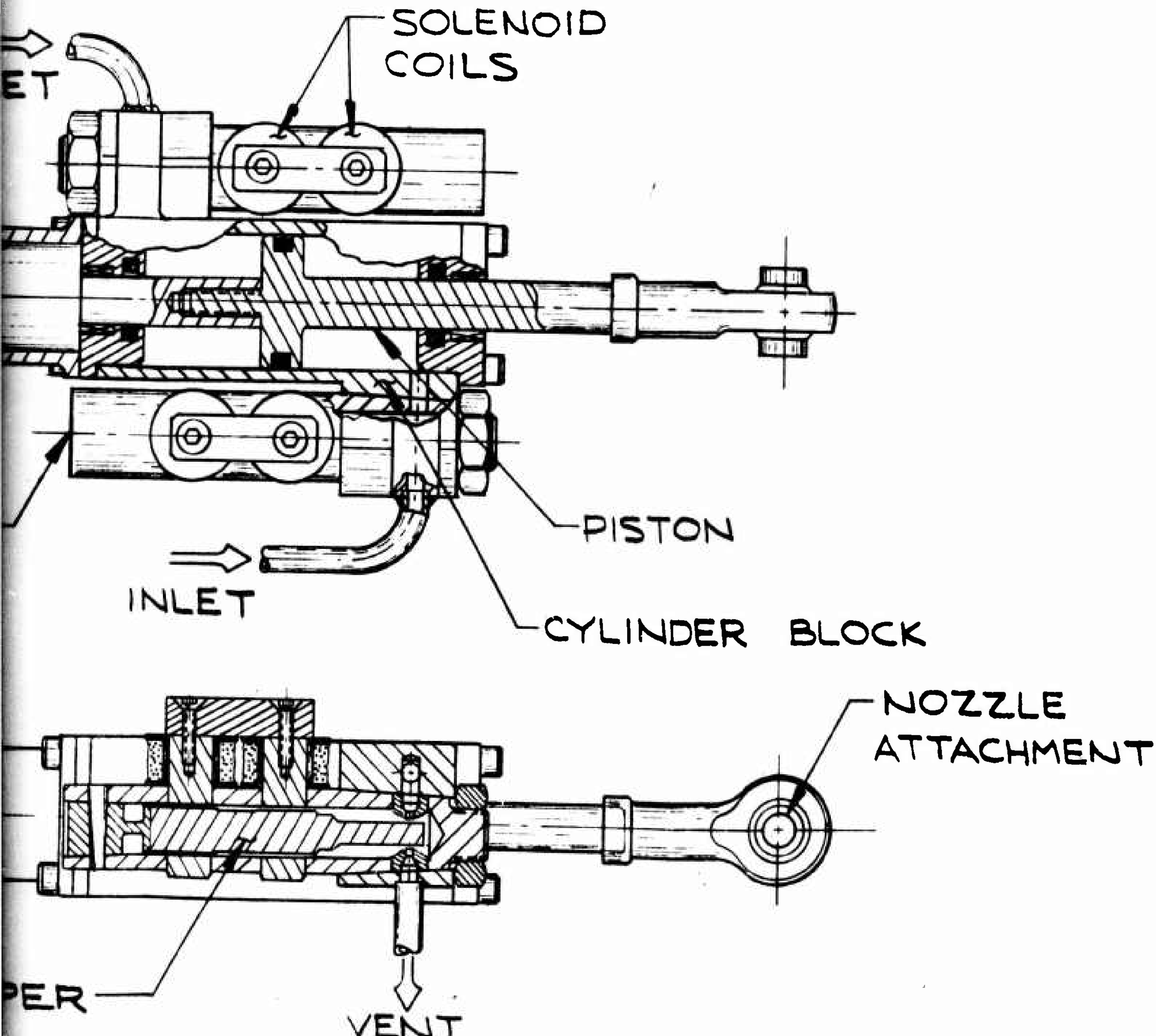


FIGURE B-4. Actuator Assembly Cro



tuator Assembly Cross-Sectional View.

2

HISTORICAL COST DATA

Aeronutronic Ford has gathered related historical cost data on a high-volume production program, the Shillelagh Missile System, which includes a control component designated the JRCA (Jet Reaction Control Assembly), a warm gas control unit with some similarities to the Servo Actuator as described below. The JRCA cost data are presented to show actual cost reduction history on a large-quantity program and Aeronutronic's high-volume-production experience.

The Shillelagh JRCA is a three-element (pitch, roll and yaw) warm gas control assembly, which includes three solenoid-operated flapper valves, a single housing, electrical coil assembly and complex plumbing. The JRCA is shown in Figure B-5. The JRCA is powered by a hot gas generator, which is not included in the JRCA costs shown below.

The Servo Actuator system includes four similar solenoid-operated flapper valves, two piston assemblies, two potentiometers, and one helium power supply assembly. The potentiometers, pistons and helium power supply are not common to the JRCA, but the Servo Actuator plumbing is less complex. A direct cost comparison is not meaningful.

The Shillelagh JRCA experienced five production buys, totalling approximately 75,000 units produced, with a yearly rate reaching 24,000 (100/day). The cost of the Shillelagh JRCA was approximately $1,800/unit in the second production buy (unit number 1,500, 1965 dollars). This cost was reduced to approximately $290/unit (unit numbers 40,000 to 58,000, 1968 dollars). These costs data are depicted as follows:

	Unit number		
	1,500	4,001-6,000[a]	40,000-58,000[b]
Shillelagh JRCA (actual)	$1,800		$ 290
Servo Actuator (estimate)			
Forward-mounted		$ 878	
Rear-mounted		$ 941	

[a]2,000 systems/year, 1976 dollars.

[b]24,000 systems/year, 1968 dollars.

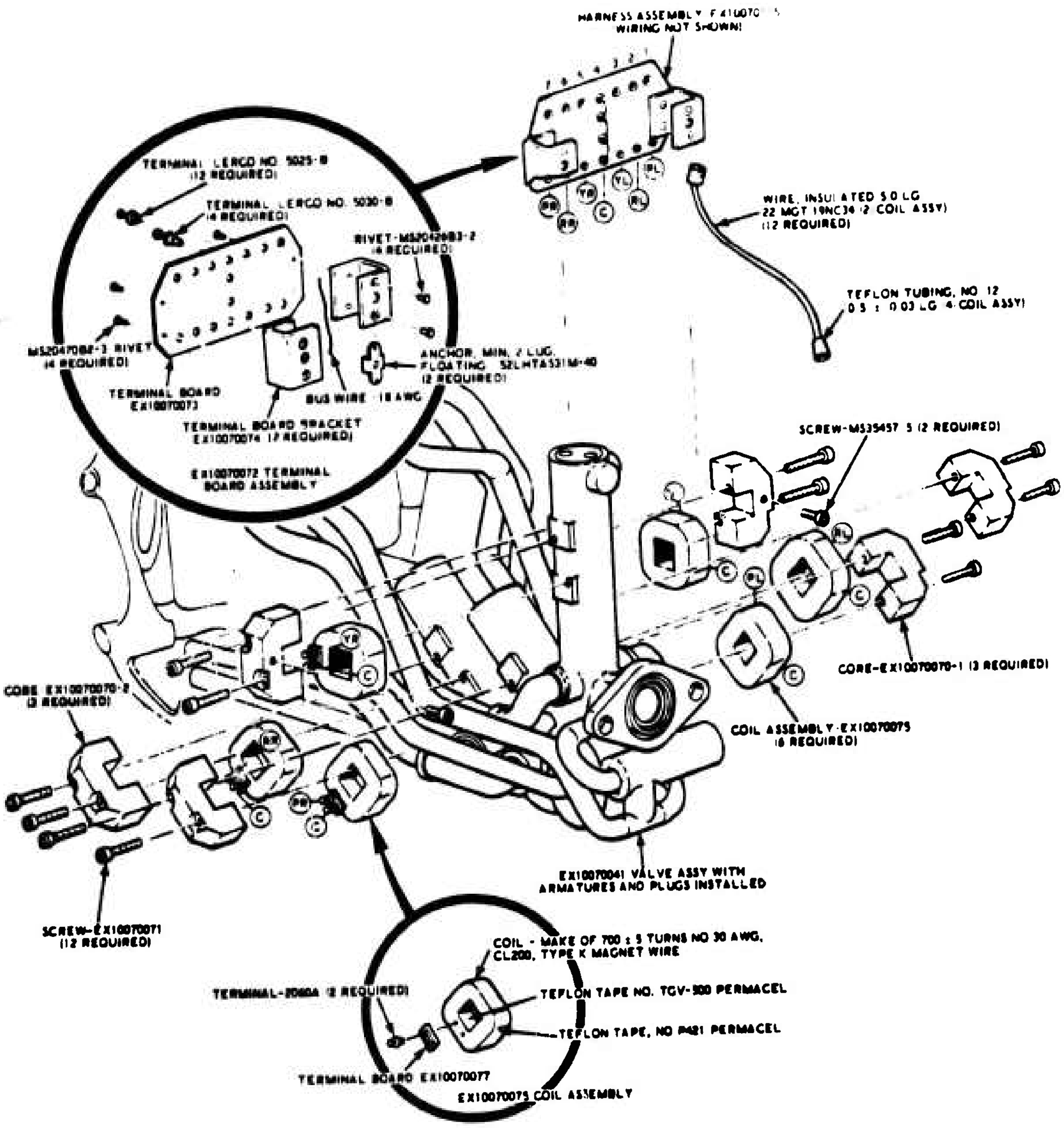


FIGURE B-5. Shillelagh Jet Reaction Control Valve (JRCA).

COSTING PREMISES

The following costing premises apply:

1. A build-up production period of two years is required prior to manufacturing systems at the quantities and rates specified in this report.

2. Non-recurring costs (special tooling and automatic tester) are not included in unit costs.

   Special tooling consists of special fixtures and tools for finish machining, gaging and assembly operation.

   A semi-automatic tester will be used for acceptance testing of actuators prior to final system assembly. Tests will include proof pressure, leakage, frequency response and slew rate.

3. Costs are based on preliminary drawings of a system that has not been production-engineered. Some production engineering assumptions, e.g., cylinder castings, have been made. Additional producibility and cost reduction studies are assumed.

4. It is assumed that Servo Actuator systems will be delivered without helium, in accordance with common practice to fill or pressurize systems at depots or missile assembly locations.

5. Fabrication and assembly estimates are for the 5,000th unit (average of units 4001 through 6000). Support labor costs were estimated for a typical, high volume production program.

6. Material estimates assume a one-lot buy sufficient for 2000 systems. These estimates were derived from prior quotations for most items using a 90% C.R.C. slope to correct for quantity differentials. Estimates, in lieu of quotations, were used for the cylinder housing, valve body and potentiometer.

7. All costs are in 1976 dollars and do not include fee.

DETAILED COST STUDY

Table B-1 summarizes the program costs for the 2,000 systems. Table B-2 is a more detailed summary of the manufacturing material costs and labor categories for the 2,000 forward-mounted systems. Tables B-3 through B-7 show the bill of material make and buy unit costs for the 2,000 units. Table B-8 is a detailed summary of the manufacturing material costs and labor categories for the 2,000 rear-mounted systems. Tables B-9 through B-14 show the bill of material make and buy unit costs.

TABLE B-1. Cost Summary.

	2000 Actuator Systems	
	Forward-mounted helium supply	Rear-mounted helium supply
Engineering hours	1018	1159
Manufacturing hours	20356	23172
Total hours	21374	24331
Engineering cost	$36,221	$41,053
Manufacturing cost	$334,167	$379,546
Total labor cost	$370,388	$420,599
Material cost	$1,385,048	$1,462,003
Total cost	$1,755,436	$1,882,602
Unit cost	$878	$941

TABLE B-2.

Fwd. Mounted Helium Power Supply

Aeronutronic

MANUFACTURING PROPOSAL SUMMARY

(DIRECT LABOR AND MATERIAL)

ITEM	MATERIAL COST AND DESCRIPTION	PURCHASED PARTS	SUBCONTRACT ITEMS	OTHER MATERIAL
1	SCRAP ALLOWANCE	% 104.0	%	% 108.0
2	C.R.C. ALLOWANCE	%	%	%
3				
4	CUM ALLOWANCE	104.0		104.0
5	BASE MAT'L $ UNIT	$ 649.37		$ 5.90
6	TOT MAT'L $ UNIT	$ 675.34	$	$ 6.39
7	PROGRAM QTY 2,000	$1,350,680	$	$ 12,740
8	VENDOR NONRECURRING			$
9	TOOL MAT'L ($ HR)			$
10	SCRAP ALLOW % ITEM 9			% $
11	SPECIAL PACKAGING MAT'L	[illegible]		$ 12,000
12	SCRAP ALLOW % ITEM 11			% $
13	SPECIAL TOOLS & GAGES			$
14		$	$	$
15		$	$	$
16	SUBTOTAL COLUMN COST	$1,350,680	$	$ 24,740
17	INBOUND FRT ALLOW. .7 %	$ 9,455	$	$ 173
18	TOTAL COLUMN COST	$1,360,135	$	$ 24,913
19	TOTAL MATERIAL COST	$ 1,385,048		

REMARKS

PROGRAM MANAGER 814 HOURS

ENGINEER 204 HOURS

MANUFACTURING AND MANUFACTURING SUPPORT LABOR SUMMARY

ITEM	DESCRIPTION	BASE VALUE	FACTOR	SUBTOTAL HOURS	TOTAL HOURS	MAN MONTHS
40	MECH. FABRICATION					
41	MECH. ASSEMBLY				11,180	67.4
42	ELECT. ASSEMBLY					
43	TOOL FABRICATION					
44						
45	TOTAL MFG LABOR				11,180	67.4
46	Q.C. TEST INSPECTION			631		
47	Q.C. LINE INSPECTION			1,345		
48	Q.C. REC. INSPECTION			448		
49	SUBTOTAL Q.C. INSP.				2,424	14.6
50	Q.C. ENGINEERING	$			780	4.7
51	MFG ENGINEERING	$			1,118	6.7
52	TOOL DESIGN					
53	PROD. CONTROL	$			2,236	13.5
54	MFG PLANS	$			224	1.3
55	MFG MANAGEMENT	$			448	2.7
56	PURCHASING	$			1,000	6.0
57	Process Control				415	2.5
58	Source Insp-QA	$			531	3.2
59	TOT. MFG SUPRT LABOR				9,176	55.2
60	TOTAL LABOR				20,356	122.6

PROGRAM: NWC SERVO ACTUATOR - 2,000/year

PAGE: 10

DESCRIPTION: Recurring Costs

REVISED BY:

CHECKED BY: DATE:

PREPARED BY: L. Jay DATE: 6/14/76

ITEM	FUNCTION / DESCRIPTION	MECHANICAL FAB. RUN %	MECHANICAL FAB. SETUP	MECH. ASSEMBLY RUN	ELECT. ASSEMBLY RUN %	RUN
61	SCRAP ALLOWANCE			104.0		
62	REWORK ALLOWANCE					
63	SUPV. ALLOWANCE			108.0		
64	C.R.C. ALLOWANCE					
65	SHOP EFFICIENCY					
66	NON S.O. CHARGES			115.0		
67						
68	CUM ALLOWANCE			129.2		
69	BASE HOURS UNIT			4.33		
70	TOT. ASSY HRS UNIT			5.59		
71	PROGRAM QTY (2,000)			2,000		
72	PROG. HRS (ITEM 70X71)			11,180		
73						
74	TOTAL HOURS			11,180		

ITEM	TOOL FAB. AND PROOF DESCRIPTION	HOURS
77	TOOL & GAGE BUILD	
78	TOOL PROOF	
79		
80		
81		
82	TOTAL TOOLING FAB.	

REMARKS

ITEM	CALENDARIZATION / PROGRAM SCHEDULE	TOTAL HRS MM
20	MECH. FABRICATION	
21	MECH. ASSEMBLY	
22	ELECT. ASSEMBLY	
23	TOOL FABRICATION	
24		
25	TOTAL MFG LABOR	
26	Q.C. TEST INSPECTION	
27	Q.C. LINE INSPECTION	
28	Q.C. REC INSPECTION	
29	SUBTOTAL Q.C. INSPECTION	
30	Q.C. ENGINEERING	
31	MFG ENGINEERING	
32	TOOL DESIGN	
33	PROD. CONTROL	
34	MFG PLANS	
35	MFG MANAGEMENT	
36	PURCHASING	
37		
38	TOT. MFG SUPRT LABOR	
39	TOTAL LABOR	

TABLE B-3.

Aeronutronic 1

MANUFACTURING PROPOSAL CONFIGURATION

PROGRAM: MISSILE CONTROL

ASSEMBLY NAME: LOW COST SERVO INSTL. FORWARD HELIUM POWER SUPPLY

ASSEMBLY NO: 50922

PAGE CODE: 1X

PAGE: 1 OF 1

NEXT ASSEMBLY NO: END ITEM

NEXT ASSY PAGE NO: -

TASK NO: 10

PART NUMBER INDENTURE (0 1 2 3 4 5 6 7 8 9)	DESCRIPTION: SOURCE REFERENCE OR MAKE PARTS MATERIAL DESCRIPTION	M B SOURCE	REF PAGE	REQ QTY THIS ASSY	PIECE COST	PURCH PARTS	SUBCONT ITEMS	OTHER: RAW MATERIAL	OTHER: PURCH SERVICE	NON-RECURRING	MECHANICAL FABRICATION RUN HRS PC	MECHANICAL FABRICATION RUN HRS ASSY	MECHANICAL FABRICATION S U HOURS	MECH ASSEMBLY RUN HRS PC	MECH ASSEMBLY RUN HRS ASSY	ELECT ASSEMBLY RUN HRS PC	ELECT ASSEMBLY RUN HRS ASSY	RUN HRS PC	RUN HRS ASSY	TOOL & GAGE DESIGN HOURS	TOOL & GAGE BUILD HRS $
5 0 9 2 2	LOW COST SERVO INSTL.																				
FORWARD MOUNTED HELIUM POWER SUPPLY		M		1											0.50						
X	PRESSURE REGULATOR																				
P.I.R # 48968		B		1	39.60	39.60															
X	SQUIB ACTUATED CUTTER																				
P.I.R. # 48970		B		1	46.80	46.80															
5 1 0 2 6	HELIUM PRESSURE BOTTLE	B		1	43.65	43.65															
X	ACTUATOR/TUBING ASSY	M	2 X	1		502.82		4.40							3.83						
X	TUBE ASSY - BOTTLE TO PRES. REG.																				
(INCLUDES CHECK-OUT PORT)		B		1	11.50	11.50															
X	TUBE ASSY - PRES. REG. TO MANIFOLD	B		1	5.00	5.00															
X	NITROGEN GAS																				
(FOR ACCEPTANCE TEST)		B		AR	1.50			1.50													
				PAGE TOTAL																	
				ASSY TOTAL		649.37		5.90							4.33						

PREPARED: P. ENGLAR DATE: 6/7/76

CHECKED BY: L. JAY DATE: 6/14/76

REVISED BY: DATE:

TABLE B-4.

Aeronutronic 1

MANUFACTURING PROPOSAL CONFIGURATION

PROGRAM:

ASSEMBLY NAME: ACTUATOR/TUBING ASSY

ASSEMBLY NO: X

PAGE CODE: 2X

PAGE 1 OF 1

NEXT ASSEMBLY NO:

NEXT ASSY PAGE NO: 1X

TASK NO: 10

PART NUMBER INDENTURE (0 1 2 3 4 5 6 7 8 9)	DESCRIPTION: SOURCE REFERENCE OR MAKE PARTS MATERIAL DESCRIPTION	M B: SOURCE	REF: PAGE	REQ: QTY THIS ASSY	DIRECT MATERIAL DOLLARS: PIECE COST	PURCH PARTS	SUBCONT ITEMS	OTHER: RAW MATERIAL	OTHER: PURCH SERVICE	NON-RECURRING	DIRECT LABOR: MECHANICAL FABRICATION: RUN HRS PC	MECHANICAL FABRICATION: RUN HRS ASSY	MECHANICAL FABRICATION: S.U. HOURS	MECH ASSEMBLY: RUN HRS PC	MECH ASSEMBLY: RUN HRS ASSY	ELECT ASSEMBLY: RUN HRS PC	ELECT ASSEMBLY: RUN HRS ASSY	RUN HRS PC	RUN HRS ASSY	TOOL & GAGE DESIGN HOURS	TOOL & GAGE BUILD HRS $
X	ACTUATOR/TUBING ASSY	M		1											0.75						
50920	ACTUATOR ASSY	M	3 X	2		492.82		4.40						1.54	3.08						
X	MANIFOLD 1" x 1" x 3" 321 STNLS STL	B		1	6.00	6.00															
X	TUBING 3/16 STNLS STL 4 PCS./SET	B		1 set	4.00	4.00															
				PAGE TOTAL																	
				ASSY TOTAL		502.82		4.40							3.81						

PREPARED: P. ENGLAR DATE: 6/7/76

CHECKED BY: L. JAY DATE: 6/14/76

REVISED BY: DATE:

ARO 5510 MAR 71

TABLE B-5.

Aeronutronic 2

MANUFACTURING PROPOSAL CONFIGURATION

PROGRAM: MISSILE CONTROL | ASSEMBLY NAME: ACTUATOR ASSY | PAGE 1 OF 1 | NEXT ASSEMBLY NO: | ASSEMBLY NO: 50920 | NEXT ASSY PAGE NO: 2X | PAGE CODE: 3X | TASK NO: 10

PART NUMBER INDENTURE (0 1 2 3 4 5 6 7 8 9)	DESCRIPTION: SOURCE REFERENCE OR MAKE PARTS MATERIAL DESCRIPTION	M B SOURCE	REF PAGE	REQ QTY THIS ASSY	PIECE COST	PURCH PARTS	SUBCONT ITEMS	OTHER: RAW MATERIAL	OTHER: PURCH SERVICE	NON-RECURRING	MECHANICAL FABRICATION: RUN HRS PC	MECHANICAL FABRICATION: RUN HRS ASSY	MECHANICAL FABRICATION: S U HOURS	MECH ASSEMBLY: RUN HRS PC	MECH ASSEMBLY: RUN HRS ASSY	ELECT ASSEMBLY: RUN HRS P	ELECT ASSEMBLY: RUN HRS ASSY	RUN HRS PC	RUN HRS ASSY	TOOL & GAGE DESIGN HOURS	TOOL & GAGE BUILD HRS $
50920	ACTUATOR ASSY	M		1											0.50						
50909	CYLINDER BLOCK	B		1	45.00	45.00															
50912 P.I.R. 29183	PISTON	B		1	10.13	10.13															
50910-1 P.I.R. 29183	END CAP	B		1	7.02	7.02															
50910-2 P.I.R. 29183	END CAP	B		1	7.02	7.02															
5091.1 P.I.R. 29183	POTENTIOMETER HOUSING	B		1	6.53	6.53															
50916	VALVE ASSY	M	4 X	2		127.44		2.20						0.52	1.04						
912635 P.I.R. 29184	POTENTIOMETER	B		1	[illegible].00	20.00															
X 3/8 - 24 JAM NUT	VALVE RETAINING NUT	B		2	0.05	0.10															
X 3/8 LOCK WASHER	VALVE RETAINING WASHER	B		2	0.02	0.04															
SFR10-32 $\frac{1}{4}$ 1/8 SEAL SCREW CO.	VALVE END PLUG	B		2	0.25	0.50															
NMB-AHFT-4 NMB	ROD END BEARING	B		1	3.25	3.25															
AJ-05-C-10 NMB	PISTON ROD BEARING	B		2	5.50	11.00															
X	O'RING, PISTON	B		1	0.15	0.15															
X	O'RING, ROD	B		2	0.10	0.20															
X	O'RING, CAP	B		2	0.10	0.20															
512546-011 SHAMBAN	GLYD RING	B		2	0.45	0.90															
512547-116N SHAMBAN	GLYD RING	B		1	0.45	0.45															
X (END CAP) 6-32 x 3/16 LONG	SCREW	B		8	0.06	0.48															
X	CASTING - CYLINDER BLOCK	B		1	6.00	6.00															
				PAGE TOTAL																	
				ASSY TOTAL		246.41		2.20							1.54						

PREPARED: P. ENGLAR, DATE: 6-7-76 | CHECKED BY: L. JAY, DATE: 6-14-76 | REVISED BY: | DATE:

TABLE B-6.

Aeronutronic

MANUFACTURING PROPOSAL CONFIGURATION 4

PROGRAM	ASSEMBLY NAME	ASSEMBLY NO	PAGE CODE
MISSILE CONTROL	VALVE ASSY	50916	4X
	PAGE: 1 of 1; NEXT ASSEMBLY NO: 50920	NEXT ASSY PAGE NO: 3X	TASK NO: 10

PART NUMBER INDENTURE (0 1 2 3 4 5 6 7 8 9)	DESCRIPTION: SOURCE REFERENCE OR MAKE PARTS MATERIAL DESCRIPTION	M/B: SOURCE	REF: PAGE	REQ: QTY THIS ASSY	DIRECT MATERIAL DOLLARS: PIECE COST	PURCH PARTS	SUBCONT ITEMS	OTHER: RAW MATERIAL	OTHER: PURCH SERVICE	NON-RECURRING	DIRECT LABOR: MECHANICAL FABRICATION: RUN HRS PC	MECHANICAL FABRICATION: RUN HRS ASSY	MECHANICAL FABRICATION: S U HOURS	MECH ASSEMBLY: RUN HRS PC	MECH ASSEMBLY: RUN HRS ASSY	ELECT ASSEMBLY: RUN HRS PC	ELECT ASSEMBLY: RUN HRS ASSY	RUN HRS PC	RUN HRS ASSY	TOOL & GAGE DESIGN HOURS	TOOL & GAGE BUILD HRS $
50916	VALVE ASSY	M		1											0.52						
50907	BODY ASSY	B	5X	1		27.00		1.10													
96002-2 P.I.R. 39262	ARMATURE (FLAPPER)	B		1	22.96	22.96															
96003 P.I.R. 39262	TIE BAR	B		1	2.66	2.66															
50773 P.I.R. 29183	RESTRICTOR	B		2	2.57	5.14															
50772	COIL ASSY	B		1	5.66	5.66															
MS24692-132	TAPER PIN	B		1	0.20	0.20															
MS16997111	4-40 SCREW	B		2	0.03	0.06															
MS122027	WASHER, LOCK	B		2	0.01	0.02															
MS27183-4	WASHER, FLAT	B		2	0.01	0.02															
					PAGE TOTAL																
					ASSY TOTAL	63.72		1.10							0.52						

PREPARED	DATE	REVISED BY	DATE
P. ENGLAR	6/7/76		
CHECKED BY: L. JAY	6/14/76		

TABLE B-7.

Aeronutronic 4

MANUFACTURING PROPOSAL CONFIGURATION

PROGRAM	ASSEMBLY NAME	ASSEMBLY NO	PAGE CODE
MISSILE CONTROL	BODY ASSY	50907	5X
	PAGE 1 of 1 / NEXT ASSEMBLY NO 50916	NEXT ASSY PAGE NO 3X	TASK NO 10

PART NUMBER INDENTURE (0 1 2 3 4 5 6 7 8 9)	DESCRIPTION: SOURCE REFERENCE OR MAKE PARTS MATERIAL DESCRIPTION	M B SOURCE	REF PAGE	REQ QTY THIS ASSY	DIRECT MATERIAL DOLLARS: PIECE COST	PURCH PARTS	SUBCONT ITEMS	OTHER: RAW MATERIAL	OTHER: PURCH SERVICE	NON-RECURRING	DIRECT LABOR: MECHANICAL FABRICATION RUN HRS PC	MECHANICAL FABRICATION RUN HRS ASSY	MECHANICAL FABRICATION S U HOURS	MECH ASSEMBLY RUN HRS PC	MECH ASSEMBLY RUN HRS ASSY	ELECT ASSEMBLY RUN HRS PC	ELECT ASSEMBLY RUN HRS ASSY	RUN HRS PC	RUN HRS ASSY	TOOL & GAGE DESIGN HOURS	TOOL & GAGE BUILD HRS $
50907	BODY ASSY	B		1	27.00	27.00															
50907-1	BODY	P_{1A}		1																	
50907-2	POLE PIECE RAW MATL. FURN. BY AERO.	P_{1A}		2																	
X	RAW MATERIAL 3115 DIA X 1 1/4" LONG 2V PERMENDUR	B		2	0.55			1.10													
					PAGE TOTAL																
					ASSY TOTAL	27.00		1.10													

PREPARED	DATE	REVISED BY	DATE
P. ENGLAR	6/7/76		
CHECKED BY L. JAY	6/14/76		

ARO 8618 MAR 71

TABLE B-8.

AFT. MOUNTED HELIUM POWER SUPPLY

Aeronutronic
MANUFACTURING PROPOSAL SUMMARY
(DIRECT LABOR AND MATERIAL)

ITEM	MATERIAL COST AND DESCRIPTION	PURCHASED PARTS	SUBCONTRACT ITEMS	OTHER MATERIAL
1	SCRAP ALLOWANCE %	104.0		108.0
2	C.R.C. ALLOWANCE %			
3				
4	CUM ALLOWANCE	104.0		108.0
5	BASE MAT'L $ UNIT	686.11	$	$ 5.90
6	TOT. MAT'L $ UNIT	713.55	$	$ 6.37
7	PROGRAM QTY 2,000	$ 1,427,100	$	$ 12,740
8	VENDOR NONRECURRING			$
9	TOOL MAT'L ($ HR)			$
10	SCRAP ALLOW % ITEM 9			% $
11	SPECIAL PACKAGING MAT'L			$ 12,000
12	SCRAP ALLOW % ITEM 11			% $
13	SPECIAL TOOLS & GAGES			$
14		$	$	$
15		$	$	$
16	SUBTOTAL COLUMN COST	$ 1,427,100	$	$ 24,740
17	INBOUND FRT ALLOW. .7%	$ 9,990	$	$ 173
18	TOTAL COLUMN COST	$ 1,437,090	$	$ 24,913
19	TOTAL MATERIAL COST	$ 1,462,003		

REMARKS
PROGRAM MANAGER 927 HOURS
ENGINEER 232 HOURS

MANUFACTURING AND MANUFACTURING SUPPORT LABOR SUMMARY

ITEM	DESCRIPTION	BASE VALUE	FACTOR	SUBTOTAL HOURS	TOTAL HOURS	MAN MONTHS
40	MECH. FABRICATION					
41	MECH. ASSEMBLY				12,800	77.1
42	ELECT. ASSEMBLY					
43	TOOL FABRICATION					
44						
45	TOTAL MFG LABOR				12,800	77.1
46	Q.C. TEST INSPECTION		714			
47	Q.C. LINE INSPECTION		11,544			
48	Q.C. REC. INSPECTION		515			
49	SUBTOTAL Q.C. INSP				2,773	16.7
50	Q.C. ENGINEERING	$			896	5.4
51	MFG ENGINEERING	$			1,280	7.7
52	TOOL DESIGN					
53	PROD. CONTROL	$			2,560	15.4
54	MFG PLANS	$			256	1.5
55	MFG MANAGEMENT	$			512	3.1
56	PURCHASING	$			1,000	6.0
57	Proc. Control-QA				481	2.9
58	Source Insp.-QA	$			614	3.7
59	TOT. MFG SUPRT LABOR				10,372	62.4
60	TOTAL LABOR				23,172	139.5

PROGRAM: NWC SERVO ACTUATOR - 2000/YEAR
PAGE: 20
DESCRIPTION: RECURRING COSTS
REVISED BY:
PREPARED BY: L. JAY
DATE: 6/14/76

ITEM	FUNCTION	MECHANICAL FAB.		MECH ASSEMBLY	ELECT. ASSEMBLY	
	DESCRIPTION	RUN	SETUP	RUN	RUN	RUN
61	SCRAP ALLOWANCE			104.0		
62	REWORK ALLOWANCE					
63	SUPV. ALLOWANCE			108.0		
64	C.R.C. ALLOWANCE					
65	SHOP EFFICIENCY					
66	NON-STD CHARGES			115.0		
67						
68	CUM ALLOWANCE			129.2		
69	BASE HOURS UNIT			4.95		
70	TOT. ASSY HRS UNIT			6.40		
71	PROGRAM QTY (2,000			2,000		
72	PROG. HRS ITEM 70X71			12,800		
73						
74	TOTAL HOURS			12,800		

ITEM	TOOL FAB. AND PROOF	HOURS
75	TOOL FAB. AND PROOF	
76	DESCRIPTION	HOURS
77	TOOL & GAGE BUILD	
78	TOOL PROOF %	
79		
80		
81		
82	TOTAL TOOLING FAB.	

REMARKS

ITEM	CALENDARIZATION / PROGRAM SCHEDULE	TOTAL HRS MM
20	MECH. FABRICATION	
21	MECH. ASSEMBLY	
22	ELECT. ASSEMBLY	
23	TOOL FABRICATION	
24		
25	TOTAL MFG LABOR	
26	Q.C. TEST INSPECTIC	
27	Q.C. LINE INSPECTION	
28	Q.C. REC INSPECTION	
29	SUBTOTAL Q.C. INSPECTION	
30	Q.C. ENGINEERING	
31	MFG ENGINEERING	
32	TOOL DESIGN	
33	PROD CONTROL	
34	MFG PLANS	
35	MFG MANAGEMENT	
36	PURCHASING	
37		
38	TOT. MFG SUPRT LABOR	
39	TOTAL LABOR	

TABLE B-9.

Aeronutronic
MANUFACTURING PROPOSAL CONFIGURATION

PROGRAM: MISSILE CONTROL

ASSEMBLY NAME: LOW COST SERVO INSTL. REAR MOUNTED HELIUM POWER SUPPLY

ASSEMBLY NO: 50921 | PAGE CODE: 1[illegible]

PAGE: 1 of 1 | NEXT ASSEMBLY NO: END ITEM | NEXT ASSY PAGE NO: | TASK NO: 20

Part Number Indenture (0 1 2 3 4 5 6 7 8 9)	Description (Source Reference or Make Parts Material Description)	M B Source	Ref Page	Req Qty This Assy	Direct Material Dollars: Piece Cost	Purch Parts	Subcont Items	Other: Raw Material	Other: Purch Service	Non Recurring	Direct Labor — Mechanical Fabrication: Run Hrs Pc	Mechanical Fabrication: Run Hrs Assy	Mechanical Fabrication: S.U. Hours	Mech Assembly: Run Hrs Pc	Mech Assembly: Run Hrs Assy	Elect Assembly: Run Hrs Pc	Elect Assembly: Run Hrs Assy	Run Hrs Pc	Run Hrs Assy	Tool & Gage Design Hours	Tool & Gage Build Hrs $
5 0 9 2 1	LOW COST SERVO INSTL. REAR MOUNTED HELIUM POWER SUPPLY	M		1											0.50						
X	ACTUATOR/TUBING ASSY	M	2 X	1		536.42		4.40							1.53						
X	SQUIB TUBING ASSY	M	6 X	1		149.69									1.62						
X	NITROGEN GAS FOR ACCEPTANCE TESTING	B		AR	1.50			1.50													
				PAGE TOTAL																	
				ASSY TOTAL		686.11		5.90							[illegible]						

PREPARED: P. ENGLAR DATE: 6/7/76
CHECKED BY: L. JAY DATE: 6/14/76
REVISED BY: DATE:

ARO 6610 MAR 71

TABLE B-10.

Aeronutronic 1
MANUFACTURING PROPOSAL CONFIGURATION

PROGRAM	ASSEMBLY NAME	ASSEMBLY NO	PAGE CODE
MISSILE CONTROL	ACTUATOR/TUBING ASSY	X----	2X
PAGE 1 OF 1	NEXT ASSEMBLY NO 50921	NEXT ASSY PAGE NO 1X	TASK NO 20

PART NUMBER INDENTURE 0 1 2 3 4 5 6 7 8 9	DESCRIPTION: SOURCE REFERENCE OR MAKE PARTS MATERIAL DESCRIPTION	M/B SOURCE	REF PAGE	REQ QTY THIS ASSY	DIRECT MATERIAL DOLLARS: PIECE COST	PURCH PARTS	SUBCONT ITEMS	OTHER: RAW MATERIAL	OTHER: PURCH SERVICE	NON-RECURRING	DIRECT LABOR: MECHANICAL FABRICATION: RUN HRS PC	MECHANICAL FABRICATION: RUN HRS ASSY	MECHANICAL FABRICATION: S U HOURS	MECH ASSEMBLY: RUN HRS PC	MECH ASSEMBLY: RUN HRS ASSY	ELECT ASSEMBLY: RUN HRS PC	ELECT ASSEMBLY: RUN HRS ASSY	RUN HRS PC	RUN HRS ASSY	TOOL & GAGE DESIGN HOURS	TOOL & GAGE BUILD HRS $
	ACTUATOR/TUBING ASSY	M		1											0.75						
50920	ACTUATOR ASSY	M	3 X	2		492.82		4.40						1.54	3.08						
X P.I.R. #48968	PRESSURE REGULATOR	B		1	39.60	39.60															
X 3/16 DIA. 321 STNLS STL	TUBING 4 PCS/SET	B		1 set	4.00	4.00															
PAGE TOTAL																					
ASSY TOTAL						536.42		4.40							3.83						

PREPARED	DATE	REVISED BY	DATE
P. [illegible]NGLAR	6/7/76		
CHECKED BY [illegible] JAY	DATE 6/14/76		

TABLE B-11.

Aeronutronic 2

MANUFACTURING PROPOSAL CONFIGURATION

PROGRAM: MISSILE CONTROL

ASSEMBLY NAME: ACTUATOR ASSY | PAGE 1 OF 1 | NEXT ASSEMBLY NO X----

ASSEMBLY NO. 50920 | NEXT ASSY PAGE NO 2X | PAGE CODE 3X | TASK NO 20

PART NUMBER INDENTURE (0 1 2 3 4 5 6 7 8 9)	DESCRIPTION: SOURCE REFERENCE OR MAKE PARTS MATERIAL DESCRIPTION	M/B SOURCE	REF PAGE	REQ QTY THIS ASSY	DIRECT MATERIAL DOLLARS: PIECE COST	PURCH PARTS	SUBCONT ITEMS	OTHER: RAW MATERIAL	OTHER: PURCH SERVICE	NON-RECURRING	DIRECT LABOR: MECHANICAL FABRICATION: RUN HRS PC	MECHANICAL FABRICATION: RUN HRS ASSY	MECHANICAL FABRICATION: S U HOURS	MECH. ASSEMBLY: RUN HRS PC	MECH. ASSEMBLY: RUN HRS ASSY	ELECT. ASSEMBLY: RUN HRS PC	ELECT. ASSEMBLY: RUN HRS ASSY	RUN HRS PC	RUN HRS ASSY	TOOL & GAGE DESIGN HOURS	TOOL & GAGE BUILD HRS $
50920	ACTUATOR ASSY	M		1											0.50						
50909	CYLINDER BLOCK	B		1	45.00	45.00															
50912 P.I.R. 29183	PISTON	B		1	10.13	10.13															
50910-1 P.I.R. 29183	END CAP	B		1	7.02	7.02															
50910-2 P.I.R. 29183	END CAP	B		1	7.02	7.02															
50911 P.I.R. 29183	POTENTIOMETER HOUSING	B		1	6.53	6.53															
50916	VALVE ASSY	M	4X	2		127.44		2.20						0.52	1.04						
912635	POTENTIOMETER	B		1	20.00	20.00															
X 3/8 - 24 JAM NUT	VALVE RETAINING NUT	B		2	0.05	0.10															
X 3/8 STD LOCK WASHER	VALVE RETAINING WASHER	B		2	0.02	0.04															
SFR10-12x58 SEAL SCREW	VALVE END PLUG	B		2	0.25	0.50															
NMB-AHFT-4 NMB	ROD END BEARINGS	B		1	3.25	3.25															
AJ-05-C-10 NMB	PISTON ROD BEARINGS	B		2	5.50	11.00															
X	O'RING, PISTON	B		1	0.15	0.15															
X	O'RING, ROD	B		2	0.10	0.20															
X	O'RING, CAP	B		2	0.10	0.20															
512546-01 SHAMBAN	GLYD RING	B		2	0.45	0.90															
512546-16N SHAMBAN	GLYD RING	B		1	0.45	0.45															
X END CAP 6-32 X 3/16 LONG	SCREW	B		8	0.06	0.48															
X	CASTING - CYLINDER BLOCK	B		1	6.00	6.00															
					PAGE TOTAL																
					ASSY TOTAL	246.41		2.20							1.54						

PREPARED	DATE	REVISED BY	DATE
P. ENGLAR	6/7/76		
CHECKED BY: L. JAY	6/14/76		

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TABLE B-12.

Aeronutronic 4
MANUFACTURING PROPOSAL CONFIGURATION

PROGRAM	ASSEMBLY NAME	PAGE	NEXT ASSEMBLY NO	ASSEMBLY NO	NEXT ASSY PAGE NO	TASK NO	PAGE CODE
MISSILE CONTROL	VALVE ASSY	1 OF 1	50920	50916	3X	20	4X

PART NUMBER INDENTURE	DESCRIPTION (SOURCE REFERENCE OR MAKE PARTS MATERIAL DESCRIPTION)	M B SOURCE	REF PAGE	REQ QTY THIS ASSY	DIRECT MATERIAL DOLLARS: PIECE COST	PURCH PARTS	SUBCONT ITEMS	OTHER: RAW MATERIAL	OTHER: PURCH SERVICE	NON-RECURRING	DIRECT LABOR: MECHANICAL FABRICATION RUN HRS PC	MECHANICAL FABRICATION RUN HRS ASSY	MECHANICAL FABRICATION S U HOURS	MECH ASSEMBLY RUN HRS PC	MECH ASSEMBLY RUN HRS ASSY	ELECT ASSEMBLY RUN HRS PC	ELECT ASSEMBLY RUN HRS ASSY	RUN HRS PC	RUN HRS ASSY	TOOL & GAGE DESIGN HOURS	TOOL & GAGE BUILD HRS $
50916	VALVE ASSY	M		1											0.52						
50907	BODY ASSY	B	5 X	1		27.00		1.10													
96002-2 P.I.R. 39262	ARMATURE (FLAPPER)	B		1	22.96	22.96															
96003 P.I.R. #39262	TIE BAR	B		1	2.66	2.66															
50773 P.I.R. #29183	RESTRICTOR	B		2	2.57	5.14															
50772	COIL ASSY	B		1	5.66	5.66															
MS24692-112	TAPER PIN	B		1	0.20	0.20															
MS16997-11	4-40 SCREW	B		2	0.03	0.06															
MS122027	WASHER, LOCK	B		2	0.01	0.02															
MS27183-4	WASHER, FLAT	B		2	0.01	0.02															
				PAGE TOTAL																	
				ASSY TOTAL		63.72		1.10							0.52						

PREPARED	DATE	REVISED BY	DATE
P. ENGLAR	6/7/76		
CHECKED BY: L. JAY	6/14/76		

ARO 6610 MAR 71

TABLE B-13.

Aeronutronic 4

MANUFACTURING PROPOSAL CONFIGURATION

PROGRAM	ASSEMBLY NAME	ASSEMBLY NO	PAGE CODE
MISSILE CONTROL	BODY ASSY	50907	5X
	PAGE 1 OF 1 / NEXT ASSEMBLY NO 50916	NEXT ASSY PAGE NO 4X	TASK NO 20

PART NUMBER INDENTURE 0 1 2 3 4 5 6 7 8 9	DESCRIPTION: SOURCE REFERENCE OR MAKE PARTS MATERIAL DESCRIPTION	M B: SOURCE	REF: PAGE	REQ: QTY THIS ASSY	DIRECT MATERIAL DOLLARS: PIECE COST	PURCH PARTS	SUBCONT ITEMS	OTHER: RAW MATERIAL	OTHER: PURCH SERVICE	NON-RECURRING	DIRECT LABOR: MECHANICAL FABRICATION: RUN HRS PC	RUN HRS ASSY	S U HOURS	MECH ASSEMBLY: RUN HRS PC	RUN HRS ASSY	ELECT ASSEMBLY: RUN HRS PC	RUN HRS ASSY	RUN HRS PC	RUN HRS ASSY	TOOL & GAGE DESIGN HOURS	TOOL & GAGE BUILD HRS
50907	BODY ASSY	E		1	27.00	27.00															
50907-1	BODY	P 1 A		1																	
50907-2	POLE PIECE	P 1 A		2																	
X	RAW MATERIAL 3115 DIA. X 1 1/14" LONG PERMENDUR 2V	B		2	0.55			1.10													
					PAGE TOTAL																
					ASSY TOTAL	27.00		1.10													

PREPARED	DATE	REVISED BY	DATE
P. ENGLAR	6/7/76		
CHECKED BY: L. JAY	6/14/76		

AND 6610 MAR 71

TABLE B-14.

Aeronutronic 1
MANUFACTURING PROPOSAL CONFIGURATION

PROGRAM	ASSEMBLY NAME	ASSEMBLY NO	PAGE CODE
MISSILE CONTROL	SQUIB/TUBING ASSY	---	0X
	PAGE 1 OF 1; NEXT ASSEMBLY NO 30921	NEXT ASSY PAGE NO 1	TASK NO 20

PART NUMBER INDENTURE (0 1 2 3 4 5 6 7 8 9)	DESCRIPTION: SOURCE REFERENCE OR MAKE PARTS MATERIAL DESCRIPTION	M B: SOURCE	REF: PAGE	REQ: QTY THIS ASSY	DIRECT MATERIAL DOLLARS: PIECE COST	PURCH PARTS	SUBCONT ITEMS	OTHER: RAW MATERIAL	PURCH SERVICE	NON-RECURRING	DIRECT LABOR: MECHANICAL FABRICATION: RUN HRS PC	RUN HRS ASSY	S U HOURS	MECH ASSEMBLY: RUN HRS PC	RUN HRS ASSY	ELECT ASSEMBLY: RUN HRS PC	RUN HRS ASSY	RUN HRS PC	RUN HRS ASSY	TOOL & GAGE DESIGN HOURS	TOOL & GAGE BUILD HRS $
·	SQUIB/ACTUATOR ASSY	M		1											0.62						
X P.I.R. #48970	SQUIB ACTUATED VALVE	B		1	46.80	46.80															
5 1 0 2 5 P.I.R. #48969	STORAGE BOTTLE	B		3	32.63	97.89															
X 3/8" DIA. 321 STNL 4" LONG	TUBING - SQUIB TO BOTTLES 3 PCS/SET	M		1	5.00	5.00															
PAGE TOTAL																					
ASSY TOTAL						[illegible]									[illegible]						

PREPARED	DATE	REVISED BY	DATE
P. [illegible]GLAR	6/[illegible] 76		
CHECKED BY: L. JAY	DATE: 6/14/76		

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